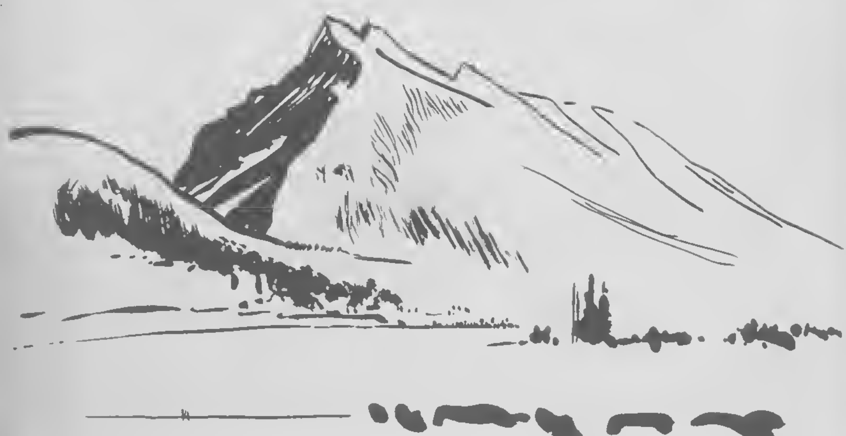
THE STORY OF THE MOUNTAINS IN BANFF NATIONAL PARK



By Helen R. Belyea

GEOLOGICAL SURVEY OF CANADA

THE STORY OF THE MOUNTAINS

BANFF NATIONAL PARK

Issued by
GEOLOGICAL SURVEY OF CANADA
Department of Mines and Technical Surveys
Ottawa

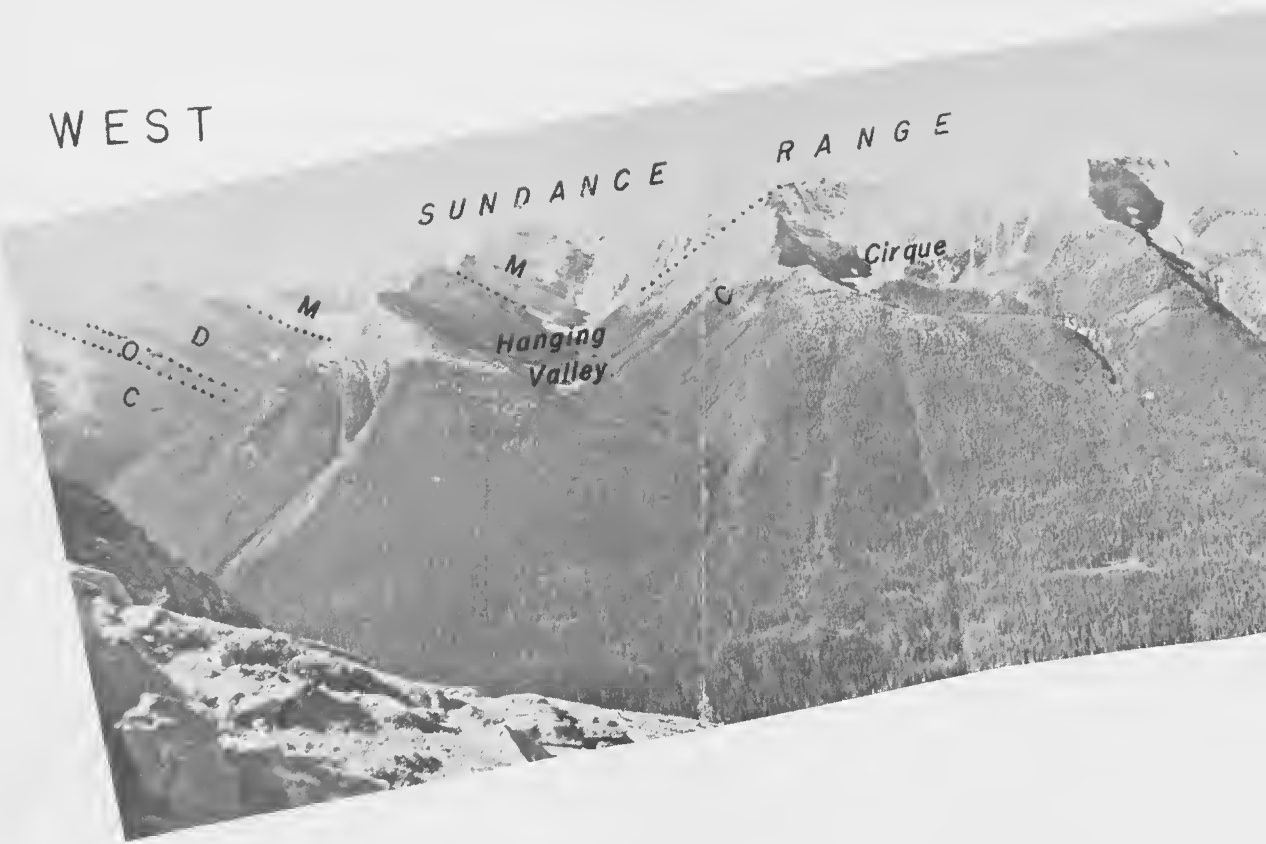
Price: 50 cents

85261-6—1

THE QUEEN'S PRINTER AND CONTROLLER OF STATIONERY
OTTAWA, 1960

Price: 50 cents · Cat. No. M40-2160

WEST




Mt. Bourgeau
Mt. Brett
M
Massive Mtn.
Pilot Mtn.
Mt. Temple
D
O
Bow River
Me
Sundance Creek

Mt. Cory
Mt. Edith
Mt. Norquay
Cascade Mtn.
Mt. Aylmer
C
D
M
Sulphur Mtn.
Me
M
M
D
Me
M
Tunnel Mtn.
M

EAST

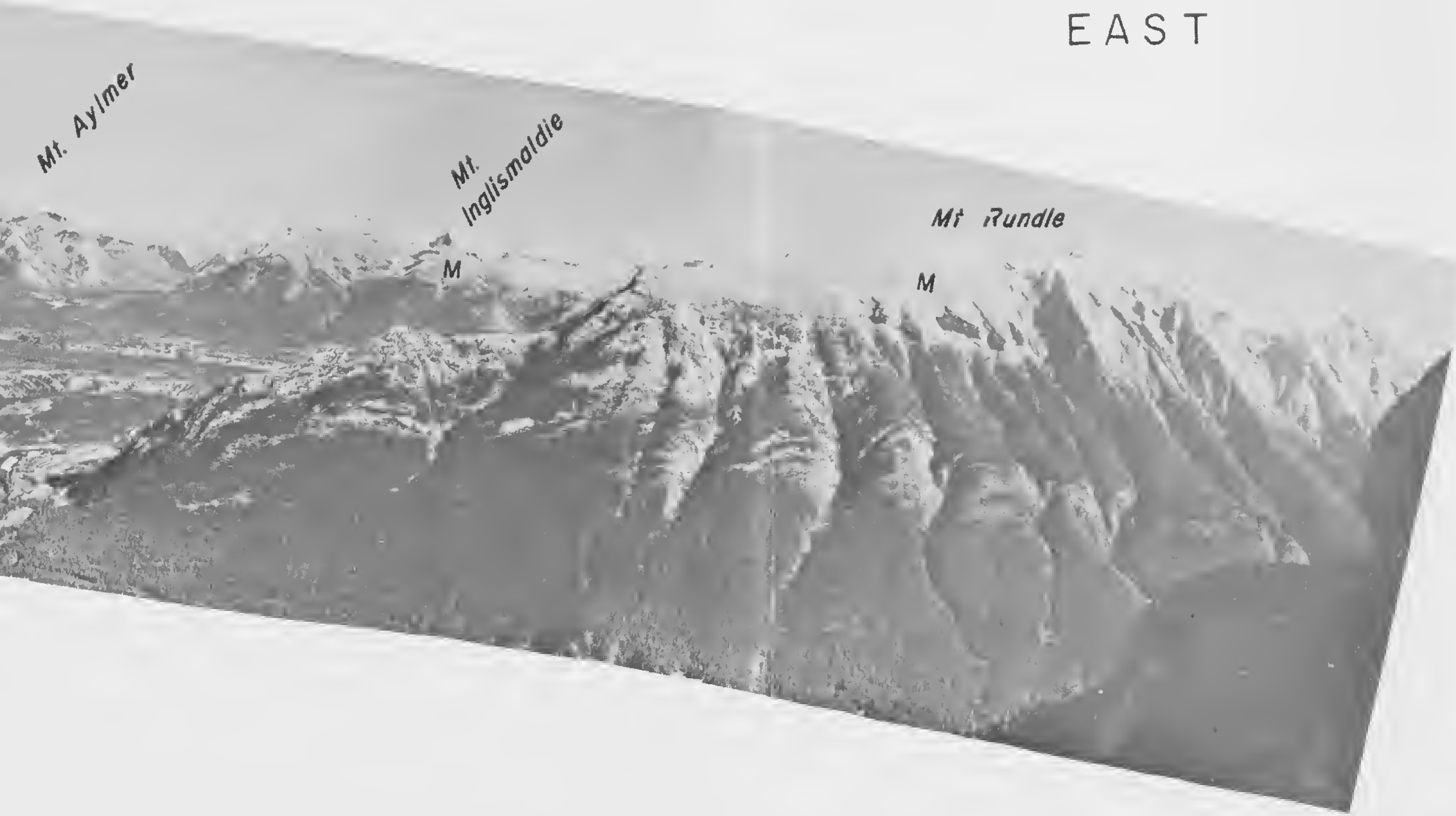


Figure 1. View from top of Sulphur Mountain. Ranges of mountains and intermontane valleys trend in a northwesterly direction. Bow River, the highways and railway line cut across the mountains 3,500 feet below and Banff nestles in the valley between Tunnel and Sulphur Mountains. The grey limestone cliffs consist of sediments deposited during the Palaeozoic, the time of ancient life. The layers of rock dip west off the peaks into the valleys. Younger rocks of the Mesozoic, the time of medieval life, underlie the valleys between the ranges. The older Palaeozoic rocks of the mountains were pushed from the west along thrust faults over the Mesozoic rocks of the valleys. The thrust faults are located approximately at the base of the grey rocks on the east face of each mountain range. The lower slopes of the mountains were smoothed by glaciers during the Ice Age but the jagged peaks projected above the ice. Numerous cirques and hanging valleys are visible from here. The following letters refer to the ages of the rock formations: C - Cambrian; O - Ordovician; D - Devonian; M - Mississippian; Me - Mesozoic.

CONTENTS

THE STORY OF THE MOUNTAINS IN BANFF NATIONAL PARK

Canada's oldest National Park lies within the eastern edge of the Rocky Mountains, and is part of that great belt of almost parallel mountain ranges that extend for nearly a thousand miles in a northwesterly direction from south of the International boundary in the State of Montana throughout the length of the provinces of Alberta and British Columbia and into the Yukon and Northwest Territories. To the east of the Rocky Mountains are the Prairies and to the west the Rocky Mountain Trench.* With peaks rising to more than 11,000 feet above sea level and deep valleys exposing great naked cliffs of rock Banff Park is an ideal place to trace the story of the mountains and to study the geological history of the Rockies.

The western boundary of Banff Park is the Great Divide and the rivers which rise in its vicinity flow into the Arctic, Atlantic and Pacific oceans. The park may be entered from the west through the Kootenay and Yoho parks in British Columbia, and from the north through Jasper Park, in Alberta.

The entrance from the east is probably the most spectacular because the mass of the Rockies is in view continuously for the beautiful approach of more than 60 miles from Calgary until the park gate is reached. The roads, one on each side of Bow River, and the Canadian Pacific Railway cut across several ranges of foothills before entering the northwesterly trending valley of the river through which they enter the park.

The answer to the question "What are these mountains and why are they here?" is a story that begins tens of millions of years

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*The Rocky Mountain Trench is a long, deep, flat-bottomed depression that extends like a great gash from Flathead Lake in Montana to the Yukon. It contains the valleys of the Kootenay, the headwaters of the Columbia, the Canol, the mighty Fraser, Parsnip, Finlay, Fox and Kechika Rivers. It separates the Rocky Mountains on the east from the remainder of the Canadian Cordillera to the west.

ago, and is written in the rocks themselves. They are the archives of the early days of the earth.

The visitor is impressed not only by the height of the mountains but also by the jagged peaks and the alternating terraces and cliffs that form them, the layers of which in some places lie flat, and in other places slope or dip into the valleys. These features will all be explained as the story develops. But, first, let us briefly examine some of the outstanding features and refer to that part of the story which explains their origin. First, the layered or terraced appearance of the mountains is caused by the layers of rock which alternate between hard, resistant strata and soft, easily weathered ones. Some are thinly layered and readily wear away to terraces, whereas others are thick and form cliffs. Originally they all lay flat under the sea. Then great earth movements lifted them to their present position bending and breaking them in the process. Bent rock layers are visible on all sides of you. With so many examples here it is impossible to mention each, but the story of how they were formed is told under the heading of The Building of the Mountains. Since the mountains first rose above sea level they have been attacked by rain, snow, frost, ice, growing plants, and running water, all of which have tried to break them apart and wear them away in a process known as erosion. The result of this erosion on the differing kinds of rock layers, folded and broken as they were during mountain building, is the jagged peak and valley sculpture that you see. These processes and their effects are more fully explained under the heading Mountain Sculpture.

The rocks that form the mountain ranges were once flat, continuous layers that spread throughout the length of the Rocky Mountains and far across what is now the Prairies where they are known from cores and cuttings taken from holes that have been drilled for oil and gas. These rock layers are also exposed at the eastern edge of the Prairies in a belt that extends from Manitoba to the Northwest Territories. When the rocks were laid down this vast area was covered by a shallow sea. We know this was so, because the rocks here in the mountains resemble very closely the sediments now being laid down on the ocean floor along the sea coast; moreover, the shells and other animal remains (fossils) in the rocks are the sea shells and sea animals of ancient times, and, in many ways, are not

unlike the animals that live in the sea today. Some of the rocks were originally deposited as sediments at the bottom of a shallow sea; others were laid down in lagoons, swamps or deltas near the sea. Some were sands, silts, and muds carried from ancient land masses by ancient rivers; others were lime or calcium carbonate deposits laid down in seas where mud was scarce and animal life prolific as it is today in shallow seas like those about the Bahamas, Florida, or Australia. These limestone rocks are composed largely of very fine limestone grains, broken up animal skeletons, sea shells (fossils) and reefs similar to the coral reefs of warm modern seas. All of these have been subjected to wave and current action and have been marked by ripples and other features like those seen on present-day beaches at low tide. The ancient sediments of the sea bottom were covered by later deposits; they were pressed down, water was squeezed out of them and they were cemented and hardened into rock. At times the sea withdrew and the rocks were exposed to the action of the weather and partly eroded, just as the mountains today are being worn away before our eyes. Some of the rocks now exposed in the mountains have been through several cycles of being covered by the sea and exposed to erosion. At the present instant in geological time, the seas are withdrawn and the rocks across the western provinces have been up-lifted and can be seen high in the mountain ranges.

The top of Sulphur Mountain provides a comprehensive view of the almost parallel northwesterly trending front ranges of the Rocky Mountains. Figure 1 shows the panorama of ranges and valleys from east to west. Also, as you turn west at the Norquay Interchange just outside of Banff you will notice that the road is crossing range after range of mountains topped by steel-grey cliffs that tower above the lower wooded slopes of the intervening (intermontane) valleys. These ranges are almost parallel: they, like the valleys between them, trend from northwest to southeast, the same trend or strike as the whole Rocky Mountain system, clearly shown on the index map.

The Front Ranges, extending from the mountain front to Mount Eisenhower, are amazingly similar both with respect to the rocks of which they are formed and to the structure which has brought the rocks into their present position. Notice the repetition of grey cliffs in the peaks and upper slopes of each range and their linear

shape. We stress the resemblances between the ranges here in order to explain the fundamental geological processes that have led to the formation of the mountains. Variations from range to range are only incidental to the main story, although they must also be taken into account to understand the detailed history of the region. For the details we refer those interested to the more technical publications listed on page 23.

THE ROCKS

The rock layers that form the mountains were originally laid down one on top of the other. In the Bow River valley, they total over 12,000 feet. They include different kinds of rock and different kinds of fossilized animal and plant remains. The animals and plants provide the main clues for determining the age of the rocks. The people who specialize in this work, the palaeontologists, can trace the development of animals and plants from the most primitive forms to the complicated mammals that now inhabit the earth. They have subdivided the sedimentary rocks that form a large part of the crust of the earth according to the animals and plants they contain. These subdivisions are shown on the Geological Time Table, along with some of the animals that characterize them. Keep this table in mind, as we will refer constantly to the subdivisions listed in it in describing the rocks. Most of these names come from areas in England, Wales and northern Europe, where the first work on the rocks was done, but you will recognize two terms, Mississippian and Pennsylvanian, from North America. Names of smaller subdivisions of the rocks, for example, Banff and Rundle, are of local origin.

The Oldest Rocks: Precambrian

In the Precambrian are included all of the rocks that were formed before animals had developed hard parts or shells that could be preserved as fossils. Towards the end of the Precambrian we find the remains of primitive forms of plant life known as algae, but little more than that. In Banff National Park, only the latest Precambrian rocks occur. These are derived from older Precambrian rocks, some of which are undoubtedly present, although deeply buried beneath the mountains of the park. However, they are

GEOLOGIC TIME TABLE

CENOZOIC ERA

Age of Modern Life: Continents in present-day form; mountain-building "completed"; volcanoes active.

QUATERNARY PERIOD

Ice Age; recent river gravels; erosion of mountains; dominance of man, modern animals and forests.

TERTIARY PERIOD

Rocky Mountains uplifted; sands, gravels; rise of mammals and modern plants.

70,000,000

MESOZOIC ERA

Age of Reptiles: Great seas, bordered by swamps, covered western North America.

CRETACEOUS PERIOD

Sandstones, shales, coal; last of the big reptiles and ammonites; rise of flowering plants; retreat of seas; Rocky Mountains begin to rise.

135,000,000

JURASSIC PERIOD

Shales; reptiles; ammonites.

180,000,000

TRIASSIC PERIOD

Siltstones and shales; rise of large reptiles.

220,000,000

PALAEOZOIC ERA

Time of Ancient Life: Sandstones and shales at base; time of predominantly clear shallow seas with abundance of sea life and limestone deposits in Banff National Park.

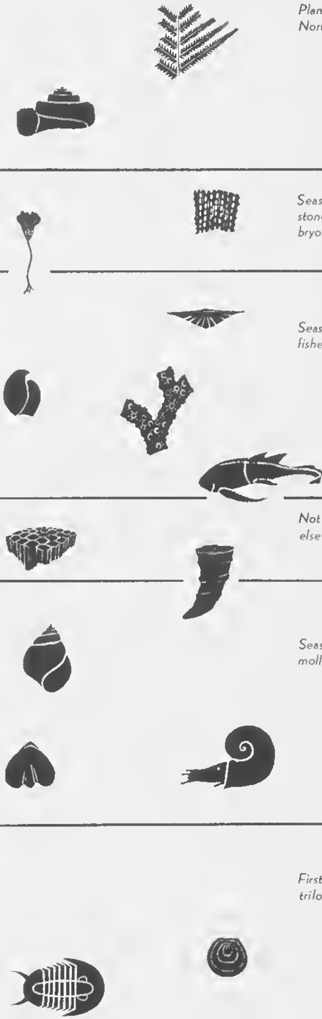
PERMIAN PERIOD

Seas restricted primitive reptiles end of Appalachian Mountain building.

275,000,000

Dates given are those of J. L. Kulp, Geological Society of America, vol. 70, p. 1634, 1959.

GEOLOGIC TIME TABLE (Continued)



Period	Years ago	Life and conditions
PENNSYLVANIAN PERIOD		*Plants, extensive coal swamps in eastern North America.*
	330,000,000	
MISSISSIPPIAN PERIOD		*Seas widespread; massive crinoidal limestone and shales; brachiopods, corals and bryozoa.*
	355,000,000	
DEVONIAN PERIOD		*Seas widespread; coralline reefs; primitive fishes and plants.*
	410,000,000	
SILURIAN PERIOD		*Not recognized in Banff National Park; elsewhere brachiopods, corals.*
	430,000,000	
ORDOVICIAN PERIOD		*Seas widespread; trilobites, brachiopods; mollusks. First fishes.*
	490,000,000	
CAMBRIAN PERIOD		*First abundant invertebrates, fossils; trilobites.*
	550,000,000	
PRECAMBRIAN ERA		*Remains of life mostly lacking; only youngest Precambrian present in the Park; fossil algae.*

found in the Precambrian Shield, where some of the oldest rocks in the world are known. Some are as old as three billion years whereas the rocks in the park are probably not much more than 550 million years old. Although it has taken over 550 million years to deposit the rocks in the park, this is only a small fraction of the time since the first rocks were formed early in the Precambrian.

The Precambrian in the park consists of purplish, greenish and reddish grey, thinly layered rocks known as shales or argillites. They were originally deposited in the sea as layers or "beds" of mud, that hardened into shales and even more so into argillites. The sheen of the rocks is due to the development of fine mineral grains called micas. Good exposures of this rock occur on Route 1A near the western junction with Route 1, and at the traffic overpass of the Trans-Canada (Route 1) and Banff-Jasper highways. Here they are tilted into the position in which they were left when the mountains were built. The smooth, inclined surfaces in the road-cuts are known as bedding planes. On the mountain sides the Precambrian rocks form gentle slopes covered with trees or talus as on Storm Mountain (Figure 2), Mount Eisenhower (Figure 3) and the Waputik Range (Figure 29).

Time of Ancient Life: Palaeozoic

During this time various forms of life developed. Examples are shown on the Geological Time Table. The rocks of this era are subdivided on the basis of the kind of life they contain. These subdivisions shown on the Time Table are important in Banff National Park because they are the rocks that form the mountains. With a little practice you will be able to pick out some of the rock systems as they are repeated in the different ranges.

Cambrian

Overlying the Precambrian rocks in the main ranges, that is, from Mount Eisenhower west over the Continental Divide, are rocks of the oldest part of the Palaeozoic era, the time of 'ancient life'. These belong to the Cambrian period, and contain the earliest known animal life on earth. For convenience, the Cambrian is subdivided

into lower, middle, and upper. These subdivisions are useful to us because each consists of a different kind of rock, of different colors and each is affected differently by the weather. Hence, they produce mountains of differing colors and shapes.

The Lower Cambrian consists of pink and purple, tightly cemented sandstones known as quartzites, and green and purple shales. In places the quartzites contain pebble beds. These beds form the lower, tree-covered slopes of the peaks on both sides of the Bow River valley. They are overlain by Middle Cambrian shales, limestones and dolomites (chemically, a limestone is calcium carbonate, and a dolomite is calcium magnesium carbonate). These rocks resist erosion and hence stand up as steep cliffs, very prominent in the main ranges, and form the peaks of many mountains in the area from Mount Eisenhower to Lake Louise (Figure 3). The soft shaly rocks that make the break in the cliff contain the famous trilobites, ancient animals reminiscent of our crayfish. A locality famous for trilobites is on Mount Stephen in Yoho National Park.

The Middle Cambrian is overlain by Upper Cambrian. The lower part of the Upper Cambrian is dominated by brightly colored shales that frequently contain casts of salt crystals and mud cracks, which make the geologist believe that these layers were formed in very shallow bays or lagoons where the climate was hot and dry. These bright orange-brown layers make visible streaks on the sides of many mountains and they are seen to best advantage on the Sundance Range. The main body of the Upper Cambrian consists of layered (bedded) grey limestones and dolomites, a widespread formation that forms the main rib of the Sundance and Sawback ranges (Figure 1), and caps many mountains along the Banff-Jasper highway, for example, Mount Amery (Figure 35). Better exposures occur in Kootenay and Yoho parks where it forms the 'Rock Wall' on the east face of the Ottertail Range. It may be as much as 4,000 feet thick, and all this laid down in a sea of which the sea-floor sank as the limestone was deposited.

Ordovician

The Lower Ordovician rocks are slightly younger than the Cambrian and contain many different fossil animals. The boundary between them and the Cambrian is not always readily apparent in mountain exposures. The Lower Ordovician consists of grey, thinly bedded limestones and shales that give it a banded or striped appearance. It forms the thick grey cliff on the Sundance and Sawback ranges (Figure 1), and is well developed on Ottertail and Hawk Ridges and the Mitchell Range in Kootenay National Park. On the Banff-Jasper highway it first appears north of Bow Pass, and forms Mounts Murchison, Wilson and Sarbach. Watch for it in roadside exposures and low knobs north to Sunwapta Pass.

Rocks of the Middle and Upper Ordovician and Silurian are only sparingly present in Banff National Park, the main representative being the Upper Ordovician Mount Wilson quartzite which forms a distinct band on Mount Murchison and the top cliff on Mount Wilson, where it is 550 feet thick (Figure 4). This thick lense of rock pinches out rapidly in all directions.

Devonian

The Devonian and the overlying Mississippian rocks make up the major part of all the mountain ranges from the mountain front to Mount Eisenhower. They are perhaps best seen from the top of Sulphur Mountain (Figure 1), but from the road in the Bow River valley one can sce the characteristic profile they impart to the mountains. Take, for example, Mount Rundle (Figures 8 and 27) or Cascade Mountain (Figure 5). Mississippian rocks form the peaks: massive grey cliffs, known familiarly as the Rundle formation and the brown, layered slope called the Banff formation. Below comes the Devonian: the sheer grey cliff of the Palliser formation, and below it the brown slope of the Alexo and Fairholme. In places a layer of black shale may be seen to separate the Palliser (Devonian) from the overlying Mississippian. Watch for the repetitions of this rock sequence in all of the Front Ranges.

The lower part of the Devonian, the Fairholme, consists of dolomite, that is, a limestone with magnesium in it. These rocks are particularly interesting because they contain reefs, shell debris and limy muds that are comparable in many ways to the reefs and coral sands of the coast of Florida, Bermuda, the Bahamas, or other West Indian islands, Hawaii or the islands of the Pacific. One may imagine a similar setting at the time these rocks were deposited. Though corals are found in these rocks, the most prolific creature at that time was the stromatoporoid, now extinct (see Figure 6). Relicts of it may be seen along Route 1A at about mile 14 west of the park, and again just below Sunwapta Pass. Mostly the skeleton has washed out leaving only holes in the rocks. This reef formation is famous for its production of large quantities of oil and gas where it extends under the Alberta plains to form the reservoir for many oil and gas fields including Leduc, Redwater, Golden Spike, Sturgeon Lake, etc.

The same Devonian formations are particularly interesting in the Sunwapta Pass area, specifically, immediately above the road on the lower slopes of Cirrus Mountain and on the 'big hill' over which the road winds to Sunwapta Pass. Here, (Figure 7) we see at the base of the Devonian, the dark brown limestones that, on close inspection, are seen to be made up almost entirely of fossil organisms, mostly the extinct stromatoporoid, but also small corals and numerous shellfish. This formed the platform for the reefs. Above it, on the big hill is a section of massive grey dolomitized limestone with great cavities, a reef similar to that producing oil at Leduc. At the foot of Cirrus Mountain are thick beds that may be interpreted as the lagoonal deposits behind the reef, and, to the northeast, on the ridge above Sunwapta Pass are shales laid down in the deep ocean in front of the reef, a situation very like that of the modern coral islands.

The Palliser limestone, although not as exotic, is more spectacular. Its great grey cliff soon becomes a familiar landmark to the observer. At its base and separating it from the Fairholme is a thin slope called the Alexo, often wooded or talus covered; this is another distinctive little rock formation.

Mississippian

The Mississippian which caps so many of the peaks in the Front Ranges and the Banff area is another magnificent rock sequence. Massive light grey limestone cliffs, the Rundle formation, stand up as rugged peaks and drop gently down the west or dip slopes of the mountains, as shown in Figure 1. It forms the great sweeping curve of the peak of Mount Rundle (Figure 8), from which it takes its name, and which is so picturesquely reflected in the Vermilion Lakes. Its rugged cliff-forming nature is even more evident on the east faces of Rundle and Cascade mountains (Figures 5 and 27). This formation is almost entirely made up of sea-shells and the debris of other sea animals. Fragments of stems and plates of the sea lily or crinoid are most abundant and may be seen in the rocks near the gondola lift on top of Sulphur Mountain. These rocks, like those of the Devonian, reflect warm sparkling shallow seas teeming with animal life. Mississippian rocks form a great reservoir for oil and gas under the plains from Alberta to Manitoba; for example, in the famous Turner Valley field and in the more recently discovered Pincher Creek and Jumping Pound gas fields.

The lower part of the Mississippian, the Banff, forms the brown slopes of alternating shales and limestones between the Rundle and the underlying grey Devonian Palliser cliff (Figure 8). In places, one may see a truly black shale (Exshaw) at the base of the Banff.

Mississippian rocks, repeated in all the ranges east of Mount Eisenhower, also form majestic mountain peaks in the Sunwapta Pass area, for example Cirrus Mountain (Figure 12) and Nigel Peak.

Pennsylvanian and Permian

These periods are represented by a relatively thin sequence of rocks containing few fossils and are not too easily separated, at a distance, from the underlying Mississippian. Known as the Rocky Mountain formation, these rocks may be seen at close quarters along the road above the dam at the end of Lake Minnewanka. They consist of dolomites (i.e., magnesium limestones), chert, sandy dolomites and highly cemented sandstones most of them with an orange or

pinkish grey color.

In Banff National Park the Rocky Mountain formation marks the end of the Palaeozoic, the time of ancient life. This was a time in which life consisted largely of shell-fish and a few primitive fishes and plants, although towards its close some forms anticipated life of the Mesozoic. The Mesozoic era, is the time of medieval life, a time of advanced plants and sea animals, but mostly known as the time when the great reptiles roamed the earth. The Geological Time Table shows some of these ancient animals. The break between the Palaeozoic and Mesozoic is, as recognized by geologists, one of the great gaps in geological history. The change from the Palaeozoic rocks to Mesozoic may be seen across the river at Bow Falls, and below the dam at the end of Lake Minnewanka.

Time of Medieval Life: Mesozoic

Triassic

The Palaeozoic formations described above form higher parts of the mountains. In the valleys between are formations of the Mesozoic era. At the base of the Mesozoic is the Triassic (Spray River formation), consisting of banded dark colored siltstones and shales that give a platy nature to the rocks. They break into natural flagstones and have been used extensively in the park for building stones, for example, the administration building and the Banff Springs hotel. These rocks contain ripple marks and other markings similar to those that can be seen today in shallow lakes or seas (Figure 10). Some layers have mud cracks, which suggest deposition in shallow water followed by exposure to the atmosphere, causing the cracks to form in the drying muds. These rocks are perhaps best seen at Bow Falls and up Spray River valley below Banff Springs hotel, as well as in road cuts near Lake Minnewanka and on the Trans-Canada Highway Routes 1 and 1A west of Mount Norquay.

Jurassic

The Jurassic consists typically of dark grey and black shales that weather to a dark brown color. In the Banff area, they occur

only in the valley between the Rundle-Cascade Ranges and the Palliser-Fairholme Ranges, that is, in the valley occupied by the Cascade River and the Bow River below (southeast of) Tunnel Mountain (see Figures 1 and 27). Even here, they come to the surface only in a few places, for example, in the narrow valley below Lake Minnewanka once occupied by the Cascade River. The Jurassic is noted for its ammonites (an ancient coiled sea animal now extinct), for its clams, the first-known birds and giant reptiles, some of which had wings.

Cretaceous

The youngest rocks to be seen in Banff Park belong to the Lower Cretaceous. These rocks are dark grey shales and sandstones with coal seams. Coal was formerly mined at the present-day ghost towns of Anthracite and Bankhead. Coal consists of the remains of plants, buried and hardened over the centuries. To account for the thick seams of coal, we must imagine luxuriant vegetation, possibly great swamps, and a warm, moist climate. Here roamed the great Cretaceous dinosaurs, browsing on the lush forest growth in the vicinity of the lagoons, swamps and rivers that existed here. Rocks of this age are exposed on steeply dipping cliffs just east of the traffic circle, at the entrance to Banff. They are better known beyond the park boundaries. Holes drilled for oil have shown that they spread eastwards beyond the mountains, under the Plains, some parts extending as far east as Manitoba.

Time of Modern Life: Cenozoic

During the late part of the Mesozoic and Cenozoic in this area, the sediments rose from sea level to their present lofty elevation as mountains. In fact, slight adjustments of the earth's crust in the mountain areas of the west are still occurring; hence occasional earthquakes occur such as the 1959 Montana earthquake, and there are a few volcanoes still active in Alaska. Once the mountains were raised, this area became one of erosion rather than deposition as the rivers cut their valleys. The chief deposits are river gravels and the debris left by the glaciers of the Ice Age.

THE BUILDING OF THE MOUNTAINS

Next comes the question "How were these rocks, once below the sea, lifted into high mountain peaks?" Compared to human life, mountains, other than volcanoes, grow slowly and nobody has seen the actual process; but geologists have deduced the story from a study of the rocks and structures. It is a complicated story, told here as briefly and as simply as possible.

We must assume that enormous forces, of almost inconceivable magnitude, have acted slowly on these rocks over eons of time, pushing them up as though pushed from the west over the prairies to the east. The story is best explained by diagrams. Figure 9 shows how geologists deduce that the rocks of Mount Eisenhower were raised from below sea level to their present position over 9,000 feet above sea level. The same story applies to all of the other ranges. Forces acting on the rocks first push them into rolling arches and troughs, called respectively anticlines (Figure 11) and synclines, and in places, into tightly folded wrinkles as on Cascade Mountain (Figure 5). Numerous examples of these structures may be seen. Notice the way the rock layers on Cascade Mountain, as seen from the top of Sulphur Mountain (Figures 1 and 5), roll over archlike, only to be cut off sharply by the valley on the east side. This is an anticline. A trough or syncline lies out of sight under the valley at this particular point, but is exposed to view on a high mountain ridge far to the southeast as one drives from the townsite to the eastern park entrance. Another anticline or arch, this one cut down the middle by the valley of the Mistaya River, may be seen from Peyto Lake lookout on the Banff-Jasper highway (Figure 13). Notice that the rock layers slope or dip away on either side of the valley and imagine that they once arched right across as a great anticlinal structure. A great synclinal or trough structure succeeds this anticline to the east. It is present in Mount Eisenhower, though not readily seen from the road. However, it may be seen on both Mount Murchison and Mount Wilson as one looks eastward down the North Saskatchewan River at the crossing on the Banff-Jasper highway and may be seen again in the peaks of Cirrus Mountain from the 'big hill' just below Sunwapta Pass, (Figure 12). You may see other examples in your trip through the park (Figure 34).

Long continuation of pressure on the rocks eventually forces the arches over until they break and the rock layers on top ride forward over the underlying layers. The planes along which the layers move are called thrust faults or, simply, thrusts. The example shown in Figure 9 shows the way the ancient rocks of Mount Eisenhower were thrust eastward over the much younger rocks in the valley between it and the Sawback Range. The same story is told by every range visible from the top of Sulphur Mountain (Figure 1) and by each range that you cross while driving up the Bow River valley from the mountain front to the Continental Divide. In all of them, the old grey Palaeozoic rocks of the bare peaks and high cliffs have been carried forward along one of these thrusts over much younger rocks now caught in the valleys between the ranges. A geological diagram showing the structure of some of the mountains west of Banff is shown in Figure 38. In some cases the forward movement of the old rocks may be measurable in tens of miles. Small wonder then, that the rock layers seen in the mountains are seldom lying flat as they were when originally deposited, but are tilted or dipping and, in places, as in the Sawback Range and Mount Edith, are very steep or vertical.

MOUNTAIN SCULPTURE

The present shape of the mountains has not been entirely determined by their structure or by the nature of the rocks, although these elements have had a strong influence. Rather, since first the rock ridges rose above sea level, they have been subjected to rain, running water, snow, ice, frost, the action of growing plants, etc. These elements, attacking the mountain, break off the large angular blocks that form the long grey fan-shaped talus or scree slopes below the cliffs on nearly every mountain. These eventually become the boulders, gravel and sand in the stream valleys. One pebble grinds against another until they are worn down to rock flour, which the streams carry onward to the sea. Rocks that you now see at Bow Summit will one day rest as silt or mud in Hudson Bay.

In our Canadian Rockies, ice has been responsible for much of the spectacular sculpture. During the Ice Age, that lasted from 1,000,000 to 10,000 years ago, more snow fell each year than the warmth of summer could melt and a great ice sheet covered most of

Canada and much of the northern United States. Only the peaks protruded as islands above the ice like those peaks that project above the ice sheets of Antarctica and Greenland today.

The ice sheet retreated and advanced several times during the Ice Age. As it advanced it covered the area like a blanket but, as it retreated, the ice funneled into valleys to form rivers of ice known as valley glaciers, which moved slowly down the mountain valleys. Some of these valley glaciers still remain such as the Saskatchewan glacier (Figure 14). Their erosive action cut away the sides of the valleys and the ice ground up the material and carried it both within and on its surface. In all cases where glaciers have been or still remain, they have eroded tremendous quantities of material from the mountains, far too much to be carried away completely by water from the melting ice. Hence much of the material was dropped at the end of the glacier as the ice melted back and forms what are called end or terminal moraines. Elsewhere, the materials, mainly gravel and mud, were pushed to the side of the glacier to form lateral moraines. Many such moraines are visible along the Banff-Jasper highway. The floor of Bow River valley itself was covered with glacial debris or drift into which it has cut its post-glacial valley, well seen in cuts on the road east of the townsite (Figure 15). The Hoodoos are formed of cemented glacial till made up of mud, sand and scattered stones (Figure 16).

One of the main valley glaciers during the Ice Age was in Bow River valley. Into it came many tributary glaciers, the valleys of which are now to be seen high on the mountains, on the Sundance Range (see Figure 1), and on many of the mountains along the Banff-Jasper highway. The continental ice sheet blocked the exits of the valley glaciers. As this ice sheet retreated the glaciers and glacial streams flowed towards the plains and deepened their valleys. The main valleys were deepened to a much greater extent than the tributary valleys. Hence, upon disappearance of the ice, valleys of tributary streams were left high on the sides of the main valleys and are accordingly known as hanging valleys. Melt water and later streams have since cut into the glacial deposits in the valleys forming terraces. Several of these terraces give the step-like ascent to the lower part of the Whitehorn Sedan lift. Several hanging valleys are visible on the

Sundance Range in Figure 1. The road to Moraine Lake (Figure 17) follows a hanging valley and gives a spectacular view over the deep U-shaped valley below. The spurs that would normally have developed between the tributaries have been truncated, leaving the mountain wall flat and smooth as may be well seen, for example, on the Waputik Range (Figure 29), or on the Sundance Range (Figure 1). The heads of the alpine glaciers cut back into the mountain walls forming amphitheatres or cirques, shaped like giant armchairs (Figure 18). Many of these along the Banff-Jasper highway are still occupied by glaciers; others are empty, only the grey moraines testifying to the former presence of the glistening blue ice. Examples of glaciers and cirques are endless here, and include Victoria Glacier at Lake Louise (Figure 19), glaciers high in the Ten Peaks above Moraine Lake, Crowfoot, Bow, Saskatchewan, Peyto, and many others unnamed.

Where glaciers have cut back simultaneously from two sides of a mountain a knife-edged ridge may be left between. The spires of Kaufman Peaks are the remnants of such a ridge. Even more striking is the horn of Mount Assiniboine left from glaciers cutting into it from all sides. This peak is visible from the top of the Whitehorn sedan lift. Figure 20 shows not only Assiniboine but also the mass of knife-edge ridges, cirques, glaciers and moraines that surround it.

As we know, the ice sheets have disappeared and the valley glaciers are relatively weak. However, great ice-fields still cover large areas in the high mountain country on the Continental Divide where there is considerable precipitation, much of it in the form of snow. One of these is the Columbia Ice-field, a tongue of which, the Athabasca Glacier, is readily accessible from the road at Sunwapta Pass at the south end of Jasper National Park. Here you may see an end moraine being formed. Other ice-fields west of Banff National Park are hidden by the high mountains but tongues from them include Bow, Crowfoot and Peyto glaciers, all visible from the Banff-Jasper highway.

Meltwaters from the glaciers form many beautiful streams and waterfalls and are the chief source of water for the great Bow and Saskatchewan river systems which rise on the Continental Divide. Where the meltwater pours into a flat valley, lovely green lakes

accumulate, most of them dammed by glacial moraines. Among these lakes are Lake Louise, Bow Lake, Hector Lake, and Peyto Lake, and many others not seen from the highway (see Figures 13, 19, 31, 32).

The glaciers alone are not responsible for all the mountain carving. The action of water itself has caused many features. Johnson's Canyon (Figure 21) is an example. In its upper reaches, Johnson's Creek flows as a small stream in a mountain valley to the top of the canyon then drops abruptly to the Bow River valley below. This is a hanging valley that was on a level with the Bow River valley during the Ice Age, an effect well seen from Eisenhower Viewpoint. Later, glaciers moving down the Bow River valley deepened it faster than the side valley was deepened and left the creek to drop over the limestone ridge to the valley below. But the massive brittle limestone rock had cracks or "joints" as a result of the stresses attendant upon mountain building. Water seeped along the joints and gradually dissolved away the limestone rock. The force of the water, especially as it carried sand and pebbles, increased the size of the joints and, dropping and swirling on its course, wore away the rock to form the canyon (Figure 21).

Channelling of running water into joints or fractures of the almost vertical cliffs of the Sawback Range has produced the spectacular cockscomb or flat-iron effect (Figure 22). Caves, for example, the 'Hole in the Wall' on Mount Cory are still another effect of water percolating through the joints of limestone rock and dissolving it away.

Landslides and avalanches are numerous in these high mountains. The dam at the end of Moraine Lake is a slide of rock from the mountain cliffs above (Figure 23). Great white scars on Protection Mountain north of Mount Eisenhower show where the rock has suddenly fallen away in what must have been a tremendous landslide. Sometimes they slide more gently and spread out into alluvial fans. A fresh one of this type on Mount Wilson is close to the Banff-Jasper highway. Indeed, many of the long, light-green slopes tonguing into the dark colors of the evergreens are old landslides. And, in early summer the rumble of snow slides and avalanches high up in the mountains near the snow fields may be heard.

DRAINAGE PATTERNS

The result of all the processes outlined above is the sculptured mountains and the valleys between. For the most part, these have determined the courses of the streams. Bow River valley is the main route through Banff National Park. The index map shows its zig-zag route for long distances through valleys parallel to the mountain chains and for short distances across the mountains. This is an ancient valley that probably grew with the mountains long before the Ice Age, and later was broadened and deepened by the ice. Its headwaters may once have been in the Lake Louise area. From here it cut back and captured the headwaters of the Saskatchewan River. Many believe that it once crossed the mountains to the Plains through the gap of Lake Minnewanka. Before the Ice Age, the river flowed between Stoney Squaw and Tunnel Mountain, but a dam of glacial debris across the old Bow River valley north of Tunnel Mountain diverted the Bow River southward to its present channel. Bow Falls (Figure 24), formed along the boundary between the Palaeozoic and Mesozoic rocks. Since their formation, Bow Falls has worn its way 100 to 200 feet upstream. It became lower in the process as its drop has been spread over a longer section of the stream. Continuation of these trends will eventually convert these falls into rapids.

The Spray River seen from Mount Norquay, also has an interesting history (see Figure 25). It may once have drained south as part of the Elk River. Later, as the Bow River cut down its valley, it captured the headwaters of the south-flowing stream and forced it to flow north. This left the headwaters ponded as the Kananaskis Lakes just outside the south boundary of the park. At that time the main stream of Spray River flowed down Sundance Valley west of Sulphur Mountain. This valley was dammed by glacial drift and the small stream in the lower Spray Valley cut through the mountain range and captured the dammed-up Spray and carried it into its present valley.

GLOSSARY OF TERMS

ABRASION: The mechanical wearing away of rocks by fragments of rock suspended in water, carried by the wind, or frozen into the sole or under side of a moving glacier or ice-sheet.

ALPINE GLACIER: A glacier occupying a depression within or lying on a mountainous terrain.

ANTICLINE: A structure resulting from the upfolding of beds into an arch-like form, so that the beds incline away from the crest to either side.

ARGILLITE: A highly cemented shaly rock. The rock breaks in planes approximately parallel to the bedding planes.

BED: A layer of rock, sharply separated by a bedding plane from its neighbors above and below.

BRAIDED STREAM: A stream flowing in several dividing and reuniting channels resembling the strands of a braid. The braided effect is caused by large amounts of gravel or other sediments deposited by the stream.

CIRQUE: A hollow of large size in the shape of a semi-amphitheatre, or armchair, excavated in mountain country by ice.

DIP: The angle at which a stratum or any plane feature is inclined from the horizontal.

DOLOMITE: A term applied to those rocks whose chemical composition is a carbonate of calcium and magnesium.

DRIFT: Any rock material, such as boulders, till, gravel, sand, or clay, transported by a glacier and deposited by or from ice or by or in water derived from the melting of the ice.

ELEVATION: Height above sea-level.

END MORAINE: A ridgelike accumulation of drift built at the end of a valley glacier or other margin of an ice-sheet.

EROSION: The processes by which earth or rock is loosened and removed from one place to another.

FAULT: A break or fracture of rock layers on which one side has been displaced relative to the other. Where one side rides up over the other it is known as a thrust fault or thrust.

FRESHET: A sudden rise in a stream or river caused by heavy rains or melting snow in the mountains or highlands.

FOLD: A bend in rock strata.

FOSSIL: The remains or traces of animals or plants that have been preserved by natural causes in the earth's crust.

GLACIER: A mass of ice, formed by the recrystallization of snow, and moving through pressure exerted upon its lower parts by weight of the overlying ice and snow.

HANGING GLACIER: A small glacier terminating on a steep slope or at the lower end of a hanging valley. Much of its wastage is through avalanching onto lower ground or a lower glacier.

HANGING VALLEY: A valley, the floor of which is notably higher than the valley to which it leads.

HOT SPRING: A spring whose water has a higher temperature than that of the human body (above 98°).

ICE-FIELD: An extensive and continuous area of thick ice, generally in mountainous terrain, and commonly supplying ice from its margin to numerous small glaciers.

JOINT: In geology, a fracture or parting which interrupts abruptly the physical continuity of a rock.

LANDSLIDE: Earth and rock which becomes loosened from a hillside by moisture or snow, and slides or falls down the slope.

LATERAL MORAINE: 1. Debris lying on the surface of a valley glacier, at or near one of its edges.
2. A drift ridge built during retreat of a valley glacier, at one of its sides.

LIMESTONE: A bedded sedimentary deposit consisting chiefly of calcium carbonate ($CaCO_3$) which yields lime when burned. Limestone is the most important and widely distributed of the carbonate rocks and is the consolidated equivalent of limy mud, calcareous sand, or shell fragments.

MORAINE: The rock material brought down by a glacier. When fragments of rock, broken off by frost and other agencies, fall down from the sides of the valley on to the ice, they form lateral moraines, one on each side of the glacier. When two glaciers meet, the two adjacent lateral moraines unite to form a medial moraine. Similarly, by the junction of more than two glaciers, two or more medial moraines may be formed. Fragments of rock which find their way to the bottom of the glacier by falling down crevasses, together with other fragments plucked from the floor of the valley, are dragged beneath the ice to form a ground moraine. At the snout of the glacier, where the ice is melting, all the transported debris is dropped to form an end moraine, which extends across the valley. Moraine differs from material brought down by water in that there is no sorting of the fragments according to size, but large boulders lie beside small chips. Moreover, the pieces of rock are angular in shape and often show scratches on the surface, the result of being dragged and not rolled along.

MUD CRACK: Crack formed by shrinkage of clay or clayey beds in the course of drying under the influence of the sun's heat.

QUARTZITE: A sandstone, usually very hard and very compact, the grains of quartz being closely pressed together and frequently cemented by secondary silica into a remarkably hard rock. Fracture occurs through the quartz grains instead of around them.

REEF: A mound-like rock structure, built by sedentary organisms such as corals, and usually enclosed in rock of a different type.

RIPPLE MARK: Corrugations in sandstones produced by the agitation of sand or silt by waves or wind when it was being deposited.

ROCK FLOUR: Finely ground rock.

SANDSTONE: A consolidated rock composed of grains of material derived from other rocks, these grains ranging from 2 1/16 mm in diameter.

SHALE: A laminated sediment, in which the constituent particles are predominantly of clay size.

SILTSTONE: A very fine-grained consolidated rock composed of particles of previously existing rocks, these particles ranging from 1/16 to 1/256 mm in diameter.

STRATA: Plural of stratum.

STRATUM: A layer of rock.

SYNCLINE: A structure resulting from the down-folding of beds which then dip inwards towards the trough, so that the lower beds surround the upper.

TALUS, or SCREE: Angular rock-debris strewn on a hillside or at the foot of a mountain.

TERMINAL MORAINE: An end moraine formed across the course of a glacier at its farthest advance, at or near a relatively stationary edge, or at places marking the termination of important glacial advances.

THRUST or THRUST FAULT: A fault along which the horizontal displacement is much greater than the vertical and therefore the fault plane has a low angle of dip with reference to the horizontal (see Fault).

TILL: A mixture of clay, silt, sand, and stones deposited directly from the ice of a glacier. It has undergone little or no transportation by water.

VALLEY GLACIER: A stream of ice moving down a valley under pressure of its own weight and the force of gravity. It may extend far below the snowline until the amount of melting is equal to the supply of ice from above. It is usually tongue-shaped, broadest at its source and tapering to a rounded snout.

REFERENCES

The general references listed here contain papers on various aspects of the geology of Banff National Park. From them, a complete bibliography can be obtained.

Alberta Society of Petroleum Geologists (1954):
Guide Book, Fourth Annual Field Conference; Banff-Golden-Radium.

Alberta Society of Petroleum Geologists (1955):
Guide Book, Fifth Annual Field Conference; Jasper National Park.

Alberta Society of Petroleum Geologists (1960):
Map No. 2 - Geology of No. 1 Highway from Exshaw, Alta. to Golden, B.C.

Camsell, Charles (1914):
Guide to the Geology of the Canadian National Parks on the Canadian Pacific Railway between Calgary and Revelstoke, 70 p.

Himus, G.W. (1954):
A Dictionary of Geology: Penguin Reference Books, 153 p.

Warren, P.S. (1927):
Banff Area, Alberta: Memoir 153, Geological Survey of Canada, Ottawa.

LOCAL POINTS OF GEOLOGICAL INTEREST

East Park Entrance to Banff Townsite

Between the east entrance and Banff townsite the Trans-Canada Highway follows the Bow River valley, the broad valley that lies between Mount Rundle to the southwest and the Fairholme Mountains to the northeast. The same valley continues to the northwest as the valley of Cascade River between Cascade Mountain and the Palliser Range, whereas the Bow turns west across the mountains at Banff (see index map). This long valley is visible from the top of Sulphur Mountain (Figure 1). It is underlain by a trough or syncline of Mesozoic rocks. The synclinal structure may be seen far to the southeast on a mountain ridge as you drive towards the east entrance of the park. Coal was mined for many years in this valley and a sign beside the railway line still marks the site of the town of Anthracite.

The mountain ranges on either side of the valley are made up of Palaeozoic (time of ancient life) limestones and shales. The rock layers of the Fairholme Range slope or dip down under the valley floor. The hard ancient Palaeozoic limestone rocks form the peaks and the younger, more easily weathered shales and sandstones of the Mesozoic (time of medieval life) are left only on the lower slopes and under the vegetation of the valley. Mount Rundle on the west, also made up of Palaeozoic limestone and shales (see Figures 26 and 27) was pushed up over the valley on the 'Rundle thrust'. The plane of this thrust is close to the road west of the bridge over Cascade River. Here, a small expanse of grey limestone 300 million years old lies only a few feet above thinly layered Cretaceous rocks, 60 million years old.

The impressive grey wall of Cascade Mountain and the waterfall that issues from a spring above it and gives the mountain its name were mentioned by all of the early explorers. This cliff is Devonian (Palliser) limestone. Higher on this mountain may be seen contortions of the rock layers (Banff) that bear evidence to the forces that raised the mountain (Figure 5).

From the road can be seen good exposures of glacial till and gravels that filled the valley during the Ice Age and into which the river has cut its course since the ice retreated (Figure 15). The geology and glacial deposits are perhaps seen to best advantage from the Hoodoos Viewpoint and nature trail.

Mount Rundle, as seen from here, displays to advantage the rock sequence that gives to all of the mountains of the Front Ranges the east-facing cliffs and relatively gentle westward slope: Figures 8, 26 and 27; the cliff-forming grey Rundle limestone at the peak, the slopes and ledges of brown Banff shales and limestones, the grey Palliser cliff, the sloping Fairholme and the Cambrian cliff near the base. These Palaeozoic rocks are thrust over the Mesozoic rocks, typically tree-covered in the valley.

Around Banff Townsite

Hoodoos Viewpoint

Here you stand on glacial till deposited at the bottom of Bow glacier (Figure 26). Bow River has incised its valley into the till since the Ice Age and now flows below you towards the viewpoint, a branch on either side of the island in the foreground. The broad valley was carved by the Bow before the Ice Age, but was widened and deepened by the scouring action of the Bow Valley glacier. The high mountain peaks were not covered but the low mountains, for example, Tunnel and Stoney Squaw, were smoothed and rounded by the ice. The floor of the valley is covered with debris composed of pebbles and rock flour ground up and carried by the ice and left when the ice melted.

The Hoodoos, Figure 16, are made of this debris that has been tightly cemented by lime in the water percolating through it, and left behind when the rest of the bed was removed by water running down the bank.

Lake Minnewanka

The road from Banff to Lake Minnewanka runs under Cascade Mountain along a deep valley, once the channel of Cascade River, and comes to a stop at the western end of beautiful Lake Minnewanka. This lake cuts abruptly across the mountain range between an unnamed peak of the Palliser Range on the north and Mount Inglismaldie on the south. It is believed to have been the pre-glacial outlet of Cascade River which now empties into the lake from the north through Stewart Canyon.

The mountains on either side of the lake are a great thrust block of Palaeozoic rocks. The Devonian (Palliser) cliff can be seen in the distance on Mount Inglismaldie and is overlain by Mississippian brown shales followed upwards by the grey limestones (Rundle) that form the peak. Warm brown rocks of the Rocky Mountain formation (Pennsylvanian and Permian) and the Triassic slope westwards off the top of Mount Inglismaldie and are exposed along the road at the end of the lake, and immediately below the dam. Here water has washed away the soil and exposed the exact contact between the Palaeozoic (time of ancient life) and Mesozoic (time of medieval life).

Bow Falls

At the falls the river follows a geologically important rock boundary (Figure 24). The cliff on the opposite side of the river is formed of sandy dolomites of the Rocky Mountain formation, which belongs to the Palaeozoic era. The cliff on the north side is composed of thinly layered sandstones of the Spray River formation which began the Mesozoic,and the channel lies in these, a type of rock more easily eroded than the former.

The surface of the rock along the road bears the marks of ripples and small waves that were imprinted on the fine sands in shallow water soon after they were deposited, just as ripple marks are formed today in shallow water of lakes or seas. Later the sands hardened under the weight of the overlying sediments, and were raised to their present position when the mountains were built.

The course of the Bow River at this point is of fairly recent age. Its history is told under Drainage Patterns in foregoing pages of this pamphlet.

Sulphur Mountain

The succession of ranges and valleys that makes up the Front Ranges of the Rocky Mountains is most easily seen from here. Figure 1 is a panorama taken from this spot. The ranges and valleys trend from southeast to northwest in parallel lines into the distance. Geologically, each range resembles the other; in each, grey Palaeozoic rocks of the mountains are thrust over younger Mesozoic rocks in the valleys to form a series of parallel thrust blocks. Details of the geology are shown in Figures 1 and 27. In the latter you may also see expressed diagrammatically the total sequence of rocks as they would be, had they not been faulted and repeated to form the succession of ranges.

At the viewpoint, you are standing on Mississippian (Rundle) rocks that continue northward to form the west peak of Mount Norquay. You can walk over the layers, or beds, of limestone rock and see scattered fragments of animals that once lived on the sea bottom. Just under the peak and clearly visible from the mountain top as well as on the way up and down, are banded brown-weathering Banff shales. These may also be seen in the distance on Mount Norquay. The black (Exshaw) shale at the base of the Mississippian is clearly exposed in the gully on Sulphur Mountain, south of the gondola lift. The lower part of the gully, though wooded, contains good exposures of the Devonian sequence. Not far above the terminal of the gondola lift is the thrust along which the Palaeozoic rocks rode over the younger, Mesozoic, rocks of the valley below. The latter, Triassic rocks of the Spray River formation, may be seen from the mountain top as steeply dipping wall-like slabs that glisten in the sunlight. It is along this thrust and the cracks in the rocks associated with it that the sulphur waters of the hot springs find their way.

The geological features visible from this viewpoint are legion. In addition to the major mountain structures discussed in the text may be mentioned the anticlinal arch of Cascade Mountain and the

synclinal valley occupied by the Bow River between the Sawback Range and Massive Mountain. On the far side of Bow River the strata can be seen to dip east towards us from Massive Mountain; on the near side the rocks dip west off Mount Cory. The layers are continuous, passing down under the valley and up on the other side making a down-fold or syncline.

In the far distance, but too far for easy observation, are the Cambrian rocks of Mount Temple and the main ranges.

The course of Bow River across the mountain ranges is best seen from this viewpoint. This river probably dates back far beyond the Ice Age to the early days of the mountains. By having an early outlet to the prairies below the mountains it maintained a higher gradient and cut its valley more swiftly than the streams in the valleys parallel to the mountains. Hence, they became tributary to the Bow. The development of the Bow River drainage and the history of its tributary streams is discussed under Drainage Patterns. It is stressed here that the Bow, a pre-glacial stream of some size, was a natural route for the alpine glaciers, and consequently, the valley has been rounded and the mountainsides smoothed. This phenomenon is plainly seen in the rounded forms of the valley walls and of Tunnel and Stoney Squaw mountains, only the high peaks remaining jagged.

A number of terraces are visible above the main valley floor. They indicate deepening and broadening of the valley by several valley glaciers, each one eroding into the floor of the valley left by the previous one. As the last continental ice-sheet on the plains melted, Bow glacier continued its downward course, deepened the valley and left the lowest of the terraces behind. During the last stages of glaciation the valley was partly filled with glacial drift. Since the Ice Age the river has cut its present steep-sided channel through the glacial till. (See also Figure 26, Hoodoos Viewpoint and a discussion of post-glacial change in drainage at Bow Falls Viewpoint).

Other features resulting from the Ice Age are exceptionally well developed on the Sundance Range. Cirques, the relatively small hollows, shaped like half of a bowl, were formed by alpine glaciers, many of which lasted high up under the mountain peaks long after the

continental ice retreated. Debris or moraines from these glaciers may still be seen in the cirques as well as great rocks slides or talus that have fallen from the cliffs. Note also that the valleys leading from the cirques have a relatively gentle slope, then suddenly drop down steeply into the valley of Sundance Creek. The mountainside between the cirque valleys is flat and triangular in shape. These valleys, that sloped gently down into other stream valleys before the Ice Age, were cut off by the large glacier flowing down Sundance Creek, leaving the tributaries high up as hanging valleys.

Mount Norquay

The winding road to Mount Norquay passes several exposures of dark grey, banded, slabby Triassic (Spray River) rocks. Near the car park are rocks of Mississippian and Pennsylvanian-Permian age, overturned by the thrust fault which has brought the Palaeozoic rocks of the peak of Mount Norquay over the rocks seen by the roadside on the way up. How this happened is shown diagrammatically in Figure 9, for Mount Eisenhower, and the same story applies here. The chair lift takes the visitor over the thrust fault and up the slope formed of Devonian (Fairholme) rocks much older than those below. Above the top of the lift, Devonian cliffs (Palliser) rise to form the east peak of the mountain. From the lift can be seen the sweep of the Rundle limestone on the peak of Mount Rundle and, below, the Banff shale, Palliser cliff and Fairholme slope (Figure 8). Far below, the valleys spread out on either side of Tunnel Mountain, and the Bow meanders on its course east of Mount Rundle. West of Mount Rundle is Spray River valley. This valley and the Bow and Sundance valleys west of Sulphur Mountain tell an interesting story of drainage changes discussed under Drainage Patterns.

Hot Springs

The Cave and Basin Hot Springs, discovered in 1883, is historically important because it led to the designation of a small area, 10 miles square, as a national park, the forerunner of the present large national park system of the Rockies. Both the Cave and Basin and Upper Hot Springs originate from rain and surface water that has seeped into fractures or pores in the rock and circulated to

depths where the temperature of the rock is high. Part of the hot water then has returned to the surface along fracture zones. On its way, it has mixed with various amounts of cool surface water, resulting in hot springs of various temperatures. It has also dissolved lime and sulphur compounds from the rocks. The lime has formed calcareous deposits called tufa around the springs and forms the wall of rock above the pool. The sulphur gives the odour to the water.

The hot springs, both at the Upper Hot Spring and at the Cave and Basin are located near the thrust fault that brought the old Palaeozoic rocks of Sulphur Mountain eastward over the Mesozoic rocks of the Spray River valley.

Banff to Eisenhower Viewpoint

From Banff townsite just west of the traffic circle one sees range upon range of mountains cut by Bow River. The road follows Bow River westwards along the deep wide channel it has cut between Mounts Sulphur and Norquay and farther west between the Sundance and Sawback ranges (see discussion of Bow River valley, under Top of Sulphur Mountain). At the foot of Sulphur Mountain across the river can be seen the buildings at the Cave and Basin Hot Springs (Figure 25). On the end of Sulphur Mountain above the Cave and Basin, in Figure 25, the lower part of the Devonian is covered by trees, but the Palliser forms a wide grey band across the mountain. Above it are rocks of Mississippian age: the tree-covered slope is Banff shale and the grey limestone at the top and forming the back slope of the mountain is Rundle limestone. The same bands of rock cross the road to Mount Norquay. Between miles 11 and 14, the road cuts through Devonian, grey Rundle limestone, Rocky Mountain group, and then dark, brownish grey, slabby shales and siltstones of Triassic (Spray River) age. To the north, Mount Edith, a jagged peak of late Devonian (Palliser) limestone, stands vertically. From here the road follows the valley between the Sawback Range, and its continuation southwards across Bow River, the Sundance Range (see Figure 1). These ranges have a thick succession of Palaeozoic rocks which dip steeply to the west so that successively younger layers of rock may be seen across the mountain front from east to west. Here we see grey and brown Cambrian, grey Ordovician, dark grey Fairholme, and light

grey massive Palliser of the Devonian separated by a thin reddish brown Alexo. The succeeding Mississippian rocks may be seen to better advantage on the Sawback Range after the road turns to follow the valley northwest (Figure 22). They occur in a road-cut between miles 16 and 17. On this range the grey Palliser limestone and the succeeding brown Banff shales and grey Rundle limestones form the jagged sawtooth ridges that run for miles in a northwesterly direction along the west side of the Sawback Range. The serrated cliffs are largely caused by weathering along joints or cracks that formed in the brittle rock when subjected to the great stress that raised them into their present steeply dipping position.

The valley of Bow River here lies in a structural trough or syncline. The rock layers on the west of the Sawback Range dip down under the valley and come up again on the west side under Massive Mountain. Pilot Mountain (Figure 28), and Mounts Brott and Bourgeau a little west of Massive Mountain, are peaks in another block of Palaeozoic rocks thrust from the west over slightly younger rocks of the Massive Range.

Route 1A turns off the Trans-Canada Highway at mile 14.3. It passes the same sequence of mountain ranges as the Trans-Canada, and gives excellent views of them. At mile 15 the road cuts through black dolomitized limestones containing an abundance of the extinct creature, the stromatoporoid. These examples are poorly preserved and have weathered into holes in the rock surface, but these are the creatures that played an important part in building the Devonian reefs so widely known for their oil production in the Alberta plains. A better example is illustrated by Figure 6.

Johnson's Canyon may be entered from Highway 1A. This canyon is cut in steep cliffs of Mississippian rock, made up of massive beds of limestone containing an abundance of fossil shells and fragments. The story of the canyon is discussed more fully near the end of Mountain Sculpture (Figure 21).

Eisenhower Viewpoint

At the viewpoint we are standing in the trough-shaped (synclinal) fold of rocks west of the Sawback Range, visible in Figure 1. The east side of the fold can be seen in the dipping rock layers of that range, and the west side can be seen on the hillside immediately to the south.

Mount Eisenhower and the mountains to the west differ somewhat in appearance and structure from the steeply dipping front ranges between here and the park entrance. They are called the main ranges of the Rocky Mountains and it is these mountains, many of which rise to more than 11,000 feet, that form the Continental Divide.

Mount Eisenhower and Helena Ridge seen from here form the eastern edge of the main ranges. This range consists of rocks older than most of those in the front ranges. As shown diagrammatically, (Figure 9), Precambrian rocks, purple and green, highly cemented shales or argillites, over 500 million years old, are the oldest rocks on this mountain range. They are overlain by Lower Cambrian quartzites (highly cemented sands) and shales which form the dark layers below the cliffs on Mount Eisenhower and Helena Ridge. The cliffs are Middle Cambrian limestones, massive, jointed rocks that tend to break away in large angular blocks and leave steep cliffs. The same rocks form many of the peaks in this area. This mass of old rocks has been pushed up along the Castle Mountain thrust, the trace of which may be seen crossing the mountain face, (see Figure 9). This is one of the great thrust faults of the Rocky Mountains. The beds above the thrust are folded down into a trough (syncline), not readily seen from here.

Eisenhower Viewpoint to Vermilion Pass

The road from the viewpoint follows the Bow River valley to Eisenhower Junction, from which the Banff-Windermere highway turns west up to the Continental Divide at Vermilion Pass between Boom and Storm Mountains. The rocks that form these mountains range from Precambrian at the bottom to Middle Cambrian in the peaks. The edge of a glacier is visible high on the top of Storm Mountain ridge (Figure 2).

From the Continental Divide the water of Altrude Creek flows east to the Bow, thence to the South Saskatchewan River and Hudson Bay; Vermilion River flows west into the Kootenay, Columbia and the Pacific Ocean.

Eisenhower Junction to Kicking Horse Pass

From Eisenhower Junction the road takes a northwesterly route up the Bow River valley; Mount Eisenhower and the Slate Mountains are to the east, and the magnificent peaks of the Bow Range to the west. Soon Mount Temple and the peaks of the Lake Louise area come into view.

Geologically speaking, the mountains on both sides of the road are similar, that is, Precambrian at the base and Middle or Upper Cambrian at the top. The outcrops of rock here and there along the road are Precambrian, purplish-grey shales over 500 million years old. Above are massive limestones and dolomites of the Middle Cambrian, tan colored rocks that form sheer cliffs on the mountain side, towers and chimneys on the mountain tops (Figure 3).

From Bow valley the Trans-Canada Highway follows Bath Creek towards Kicking Horse Pass. A good view of Bath glacier is seen en route. Kicking Horse Pass is on the Continental Divide. From the Divide the streams flow east into Bow River, thence to the South Saskatchewan and onward to Hudson Bay; Summit Lake and Sink Lake occupy a long flat upland valley in the pass and form the headwaters of Kicking Horse River, which flows westwards into Columbia River and the Pacific Ocean.

Lake Louise Area

From Lake Louise Junction and vicinity, one has a view of the majestic peaks of the main ranges, most of them of sufficient height to support glaciers. Signs indicate the names of the peaks. These ranges are carved in the warm browns and purplish grey rock of the Cambrian in contrast to the steel greys of the later Palaeozoic rocks of the front ranges. The strata lie with only a slight westward dip in the mountains to the west and all are similar geologically:

Precambrian in Bow valley and the lower tree-covered slopes, Lower, Middle and in some cases Upper Cambrian forming the cliffs and peaks. The Waputik Range, Mount Temple, the Ten Peaks, and mountains surrounding Lake Louise are typical (Figures 19, 29, 30).

The Cambrian strata are brittle rocks that tend to break into sharp-edged slabs and blocks. You may walk on paths among the blocks of an old landslide at the picnic ground at the end of Moraine Lake. Elsewhere, you may see long, steep talus slopes of this material fanning out from narrow mountain gulleys as in Figure 30.

Here, in the high peaks, the abundance of glacial features, cirques, glaciers, moraines, glacial lakes and hanging valleys, defies any attempt at enumeration, or at description of individual examples. Instead, the visitor is encouraged to observe and enjoy their beauty and, where possible, take one of the trails that lead into the glacial country. Only a few of these most frequently visited places can be described here.

Whitehorn Sedan Lift

From the top of the lift one has a magnificent view westward over the high peaks of the main ranges of the Rockies that form the Continental Divide. Far to the south the great horn of Mount Assiniboine, 11,870 feet high, stands above the other mountains. This peak (Figure 20), is the remnant left from the action of glaciers that cut in from all sides below the peak. Closer, and extending far north to Bow Peak are the sheer, east-facing cliffs of the mountains that front on the Bow River valley. All of these mountains are made up of strata of Precambrian and Cambrian age, the former underlying the valley and the lower slopes of the mountains; the latter forming the sheer cliffs. The rocks at the top of the first stage of the sedan lift are Precambrian shales and argillites. These continue upward to the top of Eagle Mountain and Mount Whitehorn. The higher peaks, Richardson, Ptarmigan, Pika and Redoubt, visible from Mount Temple ski lodge, are capped by Middle Cambrian, like Mount Eisenhower, the lower Cambrian occurring in the rounded slopes towards the base.

The trip up the sedan lift is an excellent place from which to view the terraces left by the ice and Bow River at its higher stages. The first step of the lift rises from the valley floor to the first terrace, crosses it and rises step-like up succeeding terraces, the later stages rising over bedrock cliffs.

Moraine Lake

The Lake Louise road winds up from Lake Louise Junction towards the Continental Divide. Take the turn to Moraine Lake. The road turns in a few miles into the Valley of the Ten Peaks with Moraine Creek flowing through it. This is a hanging valley and far below may be seen the valley of Bow River and Moraine Creek winding into it (Figure 17). A good view of the landslide at the outlet end of Moraine Lake is also to be had from the road.

Moraine Lake (Figure 30), despite its name, was dammed by a landslide rather than by a glacial moraine. Closer inspection of the mountains enclosing the lake show that they are composed of Lower Cambrian quartzites and hardened shales, having a network of cracks (joints), (see Figure 23). These joints, widened by the action of rain, frost, snow and ice, have allowed great blocks of rock to fall and form the heap of rubble at the outlet end of the lake and the long slopes of debris (talus) that fan outwards from the cliffs over the lower slopes of the mountains.

At least two landslides are represented in the heap of rubble at the end of the lake. The older has developed soil, lichens and vegetation, whereas the younger is bare rock and has little vegetation. The higher the source of the rock on the mountainside the farther it slid. As a result, the pinkish quartzites (highly cemented sands) from the lower cliffs are most abundant immediately under the mountain and in the talus, whereas the purplish and green shales from higher on the mountain are nearer the camp ground.

Although dammed by a landslide, the lake well deserves its name because of the excellent display of recent glacial moraines that can be seen beyond the far end of the lake (Figure 30). Some of these moraine ridges may still contain ice cores.

Lake Louise

Lake Louise (Figure 19), is surrounded by high mountains made up of rocks of Precambrian and Cambrian age. Precambrian rocks floor the valley at the outlet end of the lake. Lower Cambrian rocks top the low knobs and Middle Cambrian forms the brown glacier-spangled cliffs of the higher mountains in the distance. Mount Victoria is capped by Upper Cambrian.

The valley containing Lake Louise is much longer than it appears. It is a hanging valley, perched high above the Bow, a fact that is impressed on the visitor by the steep grades of the road. During the Ice Age, Victoria glacier extended the full length of the valley, from Victoria Mountain to the main or trunk glacier that, at that time, filled the Bow River valley below. It was fed by ice from cirques (half-bowl-shaped valleys) high in the nearby mountains. One of these cirques, Lefroy glacier, visible to the south at the far end of the lake, still supplies ice to lower Victoria glacier. Victoria glacier during the Ice Age deepened the valley and steepened its walls. Later, as the climate warmed and the ice retreated, it left the moraine ridge which dams the lake and on which the Chateau Lake Louise and other buildings now stand.

Lake Agnes, above Lake Louise to the right, is in a cirque once occupied by an alpine glacier. A trail leads to Lake Agnes and to the Plain of Six Glaciers from which a close view may be had of these features.

Banff-Jasper Highway

Lake Louise to Bow Summit

The Banff-Jasper highway turns off the Trans-Canada Highway and continues to follow the valley of the Bow River north by northwest to its headwaters at Bow Pass, 6,878 feet. Driving the Banff-Jasper highway between Bow Summit and the turn-off, you will notice a great change in the size of the river. At Bow Summit a small stream or brook builds up from a number of equally small tributaries, and runs through an alpine meadow into Bow Lake (Figure 31). This

lake receives the melt waters of Bow glacier, a tongue of the Wapta ice-field, and is the main source of water for the upper reaches of the Bow River. On its course southward the Bow receives the drainage from ice-fields high in the mountains both to the east and west of the highway. South of Bow Peak, Hector Lake, west of the highway (Figure 32) is another large glacial lake that empties into the Bow.

Throughout this section of the park, the rocks that form the mountains on either side of the Bow River valley are Precambrian and Cambrian in age. At the turn-off of the Banff-Jasper highway are outcrops of the oldest rocks in this area, the Precambrian Hector formation. These rocks are red, brown and purple argillites (hardened clay) and quartzites (tightly cemented quartz sands) that were laid down by the sea late in Precambrian time. They form the lower slopes of the mountains in the vicinity. Above, are Lower Cambrian quartzites and shales and still higher, the massive cliff-forming light brown, Middle Cambrian limestones, the continuation of those seen in Mount Eisenhower. The last are the rocks that form the sheer brown cliffs of the Waputik Range (Figure 29), Bow Peak, Mount Hector and other peaks along the route.

The structure of the Bow River valley may be readily seen between miles 16 and 20. On the east side, the rocks slope away to the east, whereas on the west side they slope to the west. The rocks forming Bow Peak lie flat between the eastward and westward sloping mountains on either side. From this it is inferred that the rocks at one time formed an arch, known as an anticline, where the valley now lies (see Figure 13). The river has carved its valley along the axis of the anticline. This is a fairly common occurrence, because the highest part of such an arch tends to develop tension cracks and fractures that allow rain, water and frost to act readily and form a channel into which still greater quantities of water drain. Thus the valley is begun and, once begun, water, snow and ice tend to concentrate in it and deepen it.

The Bow River valley was also a main channel followed by a glacier during the Ice Age and to this may be attributed the broad, U-shaped valley flanked by sheer mountain walls. It exhibits many spectacular glacial features. High on the mountains, particularly, to

the west, are cirques, many of which still contain glaciers. These cirques were cut by the action of ice and frost undermining the rock walls and carrying the debris down to form moraine ridges. Crowfoot Glacier is a good example with both lateral and end moraines visible from the highway (Figure 33). Many of these cirques are at the end of hanging valleys that emptied into the Bow when it was filled with ice. Ice moving along the main valley has truncated the spurs that would normally have developed between the valleys, thus making the flat mountain walls, for example, along the Waputik Range (Figure 29).

Many of the glaciers in the cirques and on the mountains to the west are tongues of the Waputik ice-field, high on the mountains along the Continental Divide.

Peyto Lookout, Bow Summit

A magnificent view of Peyto Lake and Mistaya valley is to be had from Peyto Lookout (Figure 13). This valley, like the upper reaches of the Bow River valley to the south, the Saskatchewan and other valleys to the north, has been carved in the centre of a rock arch or anticline. The gently sloping or dipping rock layers on either side of the valley form the flanks of the arch. The original stream valley was deepened and broadened by passage of a glacier giving it the typical U-shape. The valley floor is covered with glacial drift and gravels, examples of which may be seen in road-cuts Many tributary glaciers came into the main valley from the high mountains to the west. Peyto Glacier, a tongue of the Wapta ice-field is one of these. Peyto Glacier, which once extended beyond the end of Peyto Lake, has retreated and left debris to form the hummocky "end moraine" damming Peyto Lake. That Peyto Glacier is still contributing a large volume of debris is evident from the large delta being built at the head of Peyto Lake, clearly visible from the lookout. Above the delta is a rock ridge or threshold that the glacier was unable to destroy completely.

The orange-colored rocks at the lookout are highly cemented sandstones (quartzites) of Lower Cambrian age, approximately 500 million years old. The same rocks form the lower slopes of the mountains on either side of the valley, (for example, mile 27),

whereas the valley floor is underlain by still older Precambrian rocks. The upper slopes and ridges of the mountains are Middle and Upper Cambrian limestones.

Bow Summit to Saskatchewan River Crossing

From Peyto Lookout the road continues northwest down Mistaya valley. At Mount Patterson it passes an interesting glacier which has retreated leaving lateral and end moraines to mark the point of its greatest extent. These are sharp ridges composed of material cut away from the mountains and carried down by the ice. Many of them may still have ice cores. This is a double or 'hanging' glacier, in that it tumbles over a cliff as an ice-fall on to a lower glacier, and then again on to a still lower glacier.

The mountain ranges between Bow Summit and Saskatchewan River Crossing consist of younger rocks than those in the Bow River valley as a result of the structural plunge towards Sunwapta Pass and the Columbia Ice-fields. Little Precambrian comes to the surface north of Bow Pass. Lower Cambrian quartzites outcrop at the viewpoint and Middle and Upper Cambrian form the cliffs and peaks. Northwards, Mount Chephren, Kaufman Peaks and Mount Sarbach, west of the highway, are capped by Ordovician; Mounts Murchison and Wilson east of the highway have Upper Cambrian strata in the lower slopes, while rocks of Ordovician age make up the alternating cliffs and slopes above. A strongly cemented white sandstone, the Mount Wilson formation, of Upper Ordovician age, forms the cliff near the top (Figure 4).

The road from Bow Pass to Saskatchewan River first follows the centre of the Bow anticline, then shifts slightly towards the east limb. Hence the mountains to the west have flat layers consistent with their position in the centre of the arch, whereas those to the east dip away from the road.

A view east down the North Saskatchewan River shows the profile of a sharp downfold of strata (syncline) on both Mounts Murchison and Wilson. This is a northward continuation of that seen between Mount Eisenhower and Helena Ridge in the Bow River valley and these

mountains are all part of the same thrust block carried eastward on the Castle Mountain thrust.

Viewpoint, Saskatchewan River Crossing

From the viewpoint north of the Crossing may be seen a magnificent panorama of mountain ranges to the west. The mountains are made up of rocks of Cambrian, Ordovician and Devonian age. Most of the peaks are high and contain alpine glaciers, streams and lakes. Howse River, fed by two ice-fields west and southwest on the Continental Divide joins the North Saskatchewan River just below. The latter comes in from the northwest and turns east in its course across the mountain ranges and the prairies to Edmonton and on to Hudson Bay. The burden of gravel and sand carried by these waterways is far beyond the capacity of the river to carry farther, and hence it is dropped as bars and islands that make the typical "braided" mountain stream (Figure 34). Spring freshets move some of the materials; other rocks are moved and ground up by abrasion and gradually carried eastward by the streams; all this material carried by ice and water, is part of the erosive process which is gradually wearing down the mountains and bearing the material to its final resting place in the sea.

Saskatchewan River Crossing to Jasper National Park

From the viewpoint the road follows North Saskatchewan River valley, a deep valley, U-shaped but narrower than the valleys of the Mistaya and Bow rivers to the south. It, like the latter, also carried a glacier during the Ice Age.

The river and road continue northward along the east limit of the Bow anticline down the plunge towards Sunwapta Pass. To the east the river passes close to Mount Wilson, composed of Upper Cambrian, Ordovician and, at the top, some Devonian strata (Figure 4). West, across the river the peaks seen from the viewpoint are composed largely of Upper Cambrian and Ordovician rocks. Soon comes Mount Amery with its flat-lying Cambrian strata in the centre of the Bow anticline (Figure 35). Northwards the Upper Cambrian and Ordovician descend towards road level and make the lower knobs of

the mountains. For example, at the youth hostel on the trail to Sunset Pass the low knob is Upper Cambrian, about 1,000 feet thick. Above, are Ordovician and Devonian strata. Across the river the warm, brown-weathering shales at the base of the Upper Cambrian dip steeply northeastward off a ridge of Mount Saskatchewan, and ribbon-banded green and buff Ordovician limestones and shales are exposed in the river banks. These steeply dipping beds continue under Mounts Coleman and Cirrus (Figures 12 and 35), that is, they are the east limb of Bow River anticline. This relationship is best seen on the road coming down the hill southwards from Sunwapta Pass. These steeply dipping beds between the Bow anticline on the west and the Eisenhower syncline on the east are seen only here, and far to the south, below the southwest peak of Mount Hector. Elsewhere they have been worn away by ice and water action and now lie buried beneath the valley.

Devonian formations are clearly visible and accessible on the lower west slope of Cirrus Mountain and on the big hill over which the road climbs to Sunwapta Pass. At the base of the section is a thin white-weathering remnant of the Ordovician Mount Wilson quartzite which forms the highest ridge of Mount Wilson. Above it is a Devonian section similar to that which produces oil and gas from the Devonian reef fields under the prairies at Leduc, Redwater and Golden Spike. The reef is more fully discussed under the heading Devonian, and is illustrated by Figure 7. The Palliser cliff is like that of the front ranges in the Bow River valley (Figure 2), but is twice as thick.

Above the Devonian (Palliser) cliff on Cirrus Mountain are the thinly layered shales of the Banff formation and the overlying massive Rundle limestone (both Mississippian). Rocks of this age are also present in the Bow River valley east of Castle Mountain thrust (Figure 8). A magnificent view of this mountain (Figure 12) is obtained from the hill south from Sunwapta Pass. From here we see the whole structure: the rocks dipping eastward off Mount Saskatchewan, flattening out under Cirrus Mountain and starting to come up again on the east side, giving the synclinal, trough, or boat-shape to the mountain. This is the same syncline seen first between Mount Eisenhower and Helena Ridge, again on Mounts Murchison and Wilson at Saskatchewan River Crossing.

Near the top of the Pass, Parker Ridge south of the road leads up to Mount Athabaska, whieh rises to the west above glaeiers on all sides (Figure 36). On the east, Nigel Peak is a sharp ridge of Mississippian limestone underlain by banded shales. The grey eliff that forms a wall along the valley is the Palliser (Devonian) limestone. The road winds between Mount Athabaska and Nigel Peak over a relatively flat alpine meadow from Sunwapta Pass to the ehalet (Figure 37). This flat meadow, similar to those at Bow Pass and Kieking Horse Pass, is typieal of many of the passes in the Roeky Mountains.

Figure 2. Ridges of Storm Mountain from Vermilian Pass, Banff-Windermere highway. Hard beds of rock stand up as cliffs and soft shale layers weather back, emphasized here by the light snow covering. A glacier caps the ridge. PC, Precambrian shales; LC, Lower Cambrian quartzites and shales.

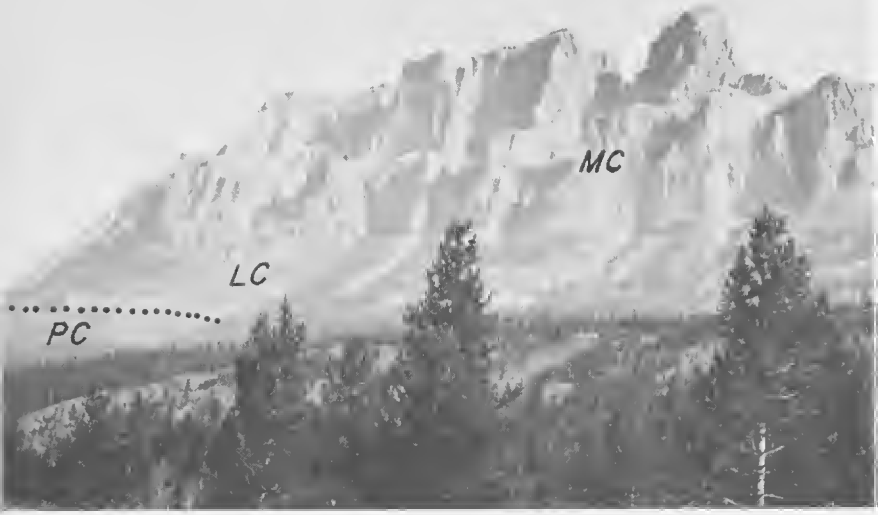


Figure 3. Maunt Eisenhower from Vermilian Pass, Banff-Windermere highway. The vertical fractures that may be seen cutting the massive beds caused blocks of rock to fall away and left the sheer cliffs. The brown cliffs are Middle Cambrian limestone (MC), broken by the shales that carry fossil trilobites. LC - Lawer Cambrian purple and green shales and pink quartzites; PC - Precambrian grey and purple sholes.

Figure 4. The stark profile of Mount Wilson exhibits the Lower Ordovician rock sequence of the Banff-Jasper highway. Tree and grass covered slopes at the base are Upper Cambrian. The cliffs are mostly massive limestone beds and the slopes are thinly layered limestones and shales. The uppermost cliff is Upper Ordovician Mount Wilson quartzite, 550 feet thick here.

Figure 5. Cascade Mauntain in winter. This mountain is made af the Devonian and Mississippian rocks characteristic of the ranges from the entrance to the mauntains an the east ta the Sawback Range on the west. Alternating hard and saft layers cause the terraces an the cliffs and slopes near the peak. Shales underlie the lang snaw-covered slope and the great cliff af resistant rock at the base is knawn as the Palliser. The rock layers slope or dip away to the west. The cascade described by the early explarers lies frozen against the Palliser cliff, right of centre.

Figure 6. Devanian reef rack composed the skeletans af the stromatoporoid, a sea animal now extinct.

Figure 7. A massive Devonian white dolomite reef in the 'big hill', Sunwapta Pass, Banff-Jasper highway. This is the same type of structure as that from which oil is produced at Leduc, Redwater, Golden Spike and other fields in Alberta. Dp - Palliser limestone; Da - Alexo; Df - Fairholme.

Figure 8. Mount Rundle, Banff. The loyers of the Mississippian Rundle formation dip westward into the Sproy River volley. The peok is Rundle limestone, the some rock formotion from which Turner Volley oil and gos field, southwest of Colgory, hos produced for mony yeors. Mr - Rundle limestone; Mb - Banff sholes; Dp - Devonion Polliser limestone cliffs.

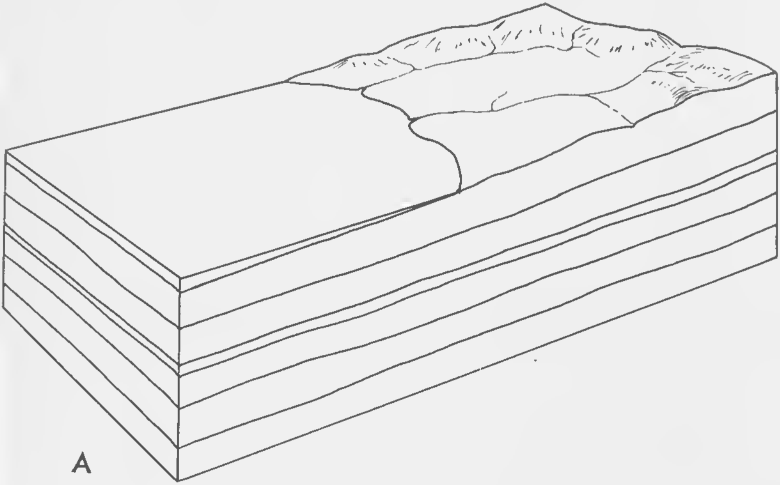
Figure 9. Mount Eisenhower as it appears today. Above the Castle Mountain thrust are Precambrian (PC) and Cambrian (LC and MC) rocks that have ridden up over late Palaeozoic (P) and Mesozoic (Me) rocks.

A. Sediments are washed into the sea by streams and rivers. Here they rest as flat layers, are covered by more sediments and are gradually cemented into rock.

B. Mountain-building forces cause the rock layers to fold into successive arches (anticlines) and troughs (synclines).

C. Increased pressure causes the rocks to break and ride up, one side over the other. The plane along which they move is called a thrust or thrust fault.

D. As mountain-building forces push the rocks above sea level, they are affected by weather and worn away into mountains and valleys. Bow River valley is eroded in the centre of the anticline where fractures have caused water to concentrate. An early Mount Eisenhower and Helena Ridge formed in the down-bent (synclinal) strata.



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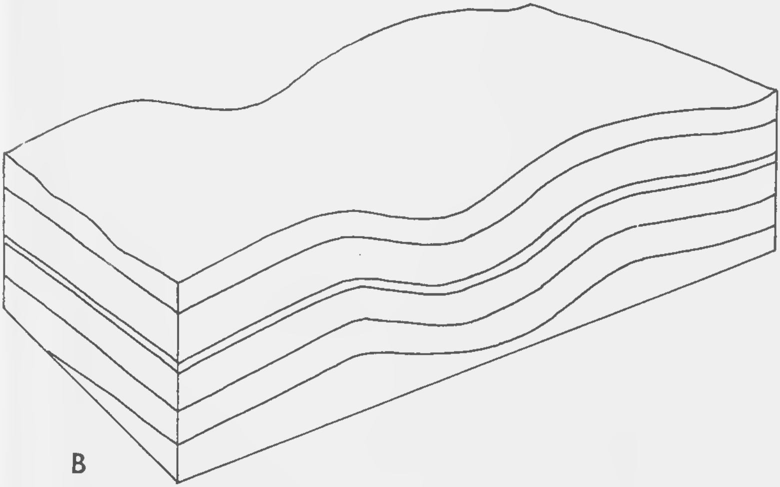

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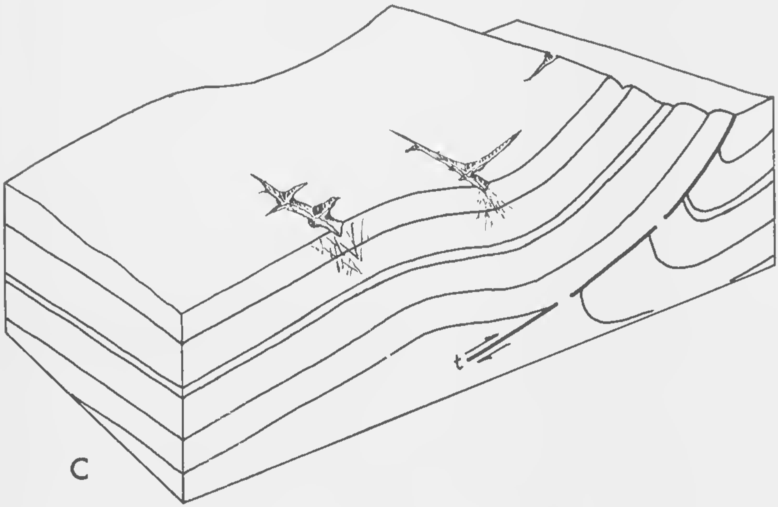

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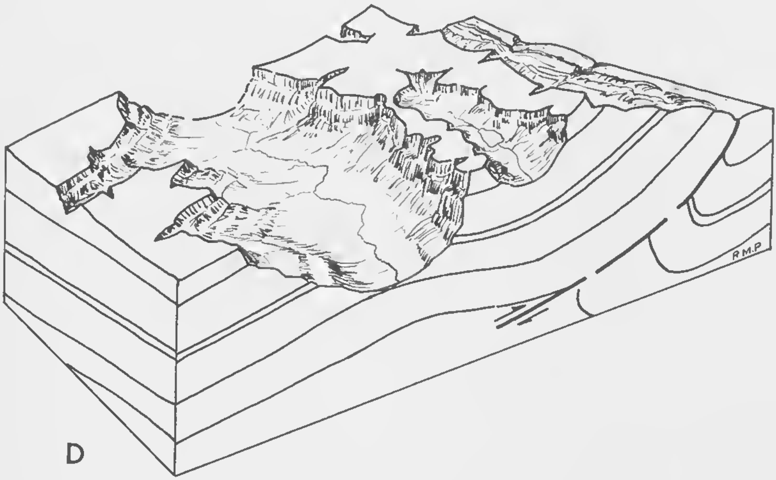

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Figure 10. Ripple-marks preserved on a rock surface are like thase caused by waves on the bottoms of lakes and along the seashore today.

Figure 11. Rock arch or anticline.

Figure 12. Cirrus Mountain, Banff-Jasper highway, os seen from near Sunwapta Pass. The rack layers bow dawn gently under the peak in the form of a syncline. Mr - Mississippian Rundle limestone; Mb - Banff shale; Dp - Devonian Palliser limestone; Df - Devonian Alexo and Foirholme.

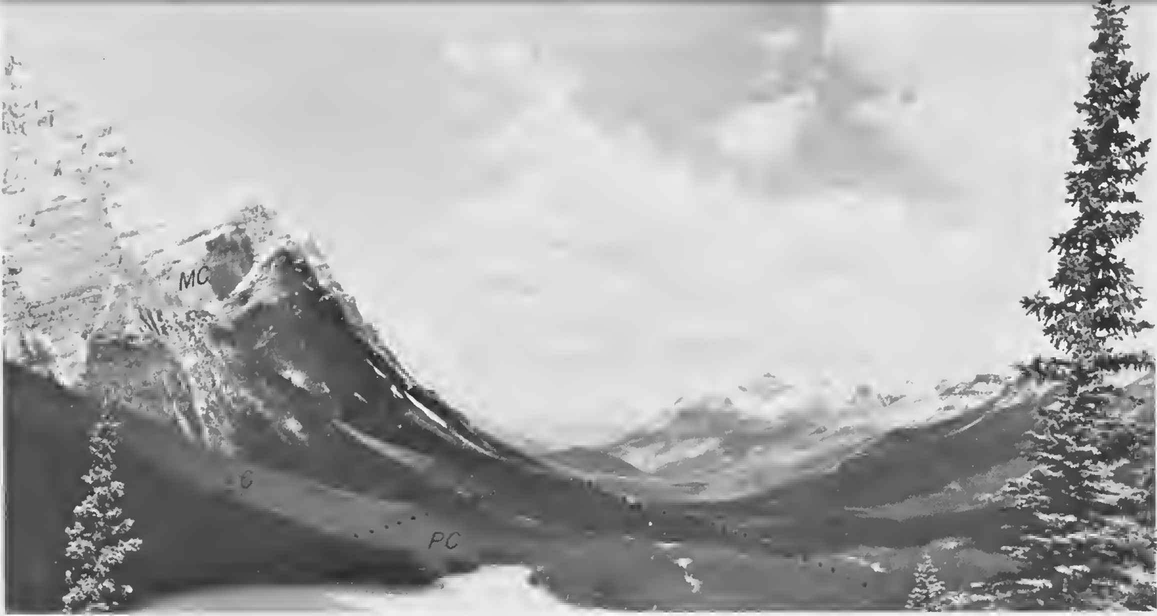

Figure 13. Peyto Lake, headwaters of the Mistaya River. This blue-green glacial lake is dammed at its lower end by a moraine dating from an early stage of Peyto Glacier. The rock layers of the mountains that now slope (dip) away from the valley on either side once arched across the valley as an anticline but were worn away by flowing water and ice.

The smooth U-shaped valley is typical of glaciated mountain valleys. PC - Precambrian; LC - Lower Cambrian; MC - Middle Cambrian.

Figure 14. Saskatchewan Glacier. This is a typical valley glacier, flawing eastward from the Columbia Icefield an the Cantinental Divide. This glacier farms the headwaters of the North Saskatchewan River which flaws from here ta Nelsan River in narthern Manitoba. The dark line winding down the middle af the glacier is moraine.

Figure 15. Cliffs of glacial debris in the Bow River valley near Banff. Hoodoos have been carved in the banks by erosion of soft mud. Gravel in the river bed is typical of mountain streams.

Figure 16. The Hoodoos at the Hoodoos Viewpoint, Banff. The Hoodoos are formed of cemented glacial till composed of mud, sand and scattered stones left behind by the glacier that once flowed down the Bow River valley.

Figure 17

Mountains along the Continentol Divide from the road to Moroine Loke. The terrace on which the rood is built is the same as that on the opposite side of the valley. It is the remnont of on eorlier glacial volley into which the stream has cut its present course, leaving the tributories in honging volleys.

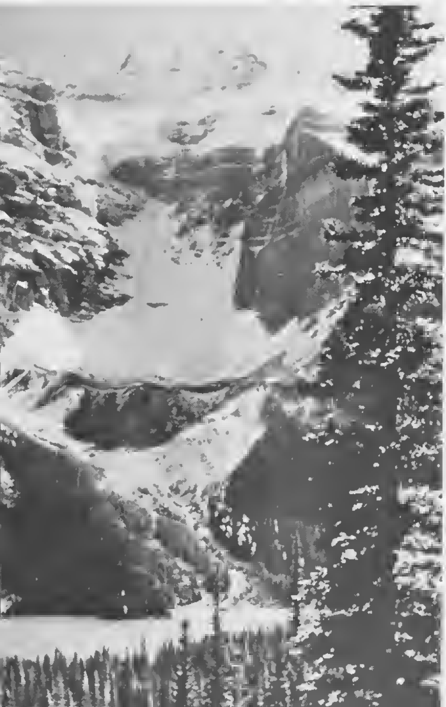

Figure 18

Cirques on Mount Fay. The cirque (centre) contains a glacier fed by ovalanches from the hanging glocier above the limestone cliffs. The gravel ridges in front of the glacier ore moraines from which material is being woshed down to form the delto in Moroine Lake.

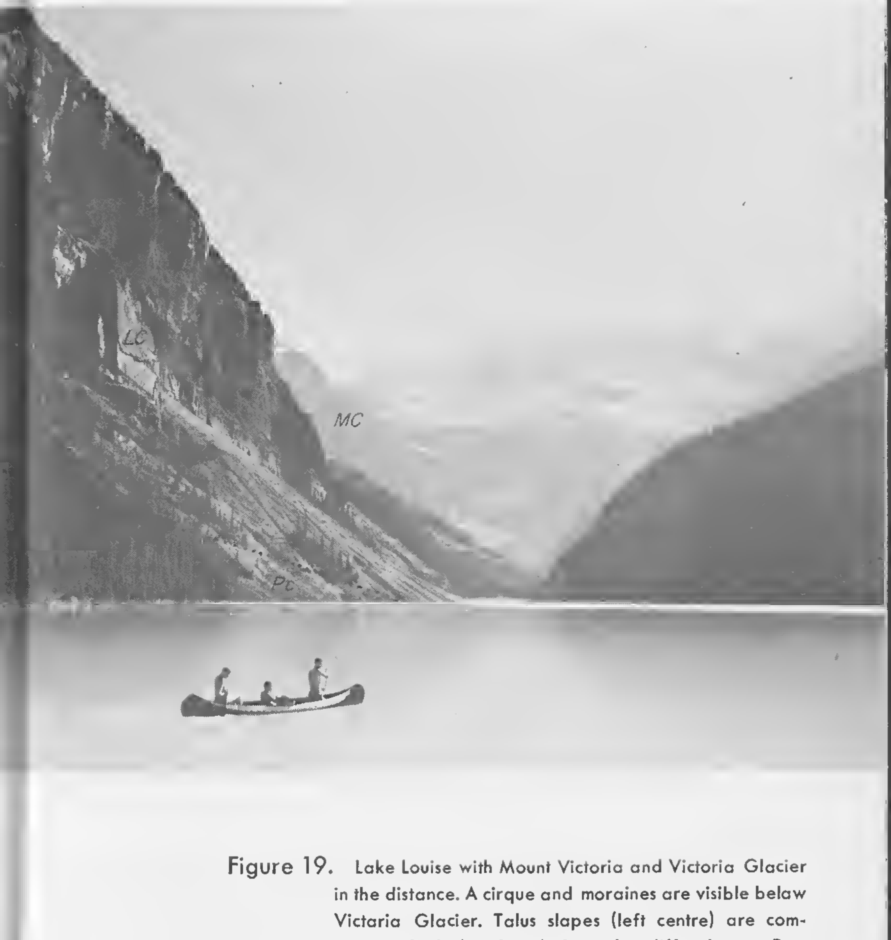

Figure 19. Lake Louise with Mount Victoria and Victoria Glacier in the distance. A cirque and moraines are visible below Victoria Glacier. Talus slopes (left centre) are composed of blocks of rock from the cliffs above. Pc - Precambrian; LC - Lower Cambrian; MC - Middle Cambrian.

Figure 20. Maunt Assiniboine. This peak, like the famous Matterhorn, was formed by cirques cutting into the mountain from all sides.

Figure 21. Johnson's Canyon. A great fracture (joint) carries Johnson's Creek. This joint in limestone rock was widened by solution ond the cutting action of water.

Figure 22. The Sawtooth Range. The sawtooth ridges were farmed by water percolating along froctures ar jaints in the steeply dipping Mississippian (M) ond Devanian (D) limestane strata.

Figure 23

The Tower of Babel and landslide damming the outlet end af Maraine Lake. The racks are Cambrian shales and sandstane depasited in thin harizantal layers or beds. Vertical cracks (jaints) farmed in the rocks when they were uplifted fram the sea. The horizontal layers and vertical joints cause the racks ta break away readily in blocks, which have fallen as landslides at variaus times.

Figure 24

Bow Falls. Baw River and Falls here fallaw the baundary between the Mesazaic, Triassic rocks (left af falls) and the Palaeozoic, Permian, Pennsylvanian and Mississippian rocks (right). The Triassic rocks are used as building stane, far example, in the Banff administration building and the Banff Springs hotel.

Figure 25. Sulphur Mountain, Spray and Sundance valleys from Mount Narquay with Bow River valley in the foreground. These valleys have a history of stream piracy. The Bow River, as the main stream, cut its valley most rapidly and the waters in the valley east of Sulphur Mountain (the present Spray River) flowed into it. The valley west of Sulphur Mountain (Sundance Creek, now), where once flowed a large stream, the early Spray, was choked by glacial drift. As a result the stream in the lower Spray River valley cut the gap between Sulphur and Goat ranges and captured the headwaters of the Spray, deflecting the main stream to the east of Sulphur Mountain. Hence we find little Sundance Creek occupying the broad valley west of Sulphur Mountain.

Figure 26. Sketch af view from Hoodoos Viewpoint. Yau look directly west up Baw River valley. The raad fallaws the river across the mauntain range. These ranges are thrust blacks af which the scarps face east and the rack layers dip westward. The terraces an which yau stand and on either side of the valley are glacial drift.

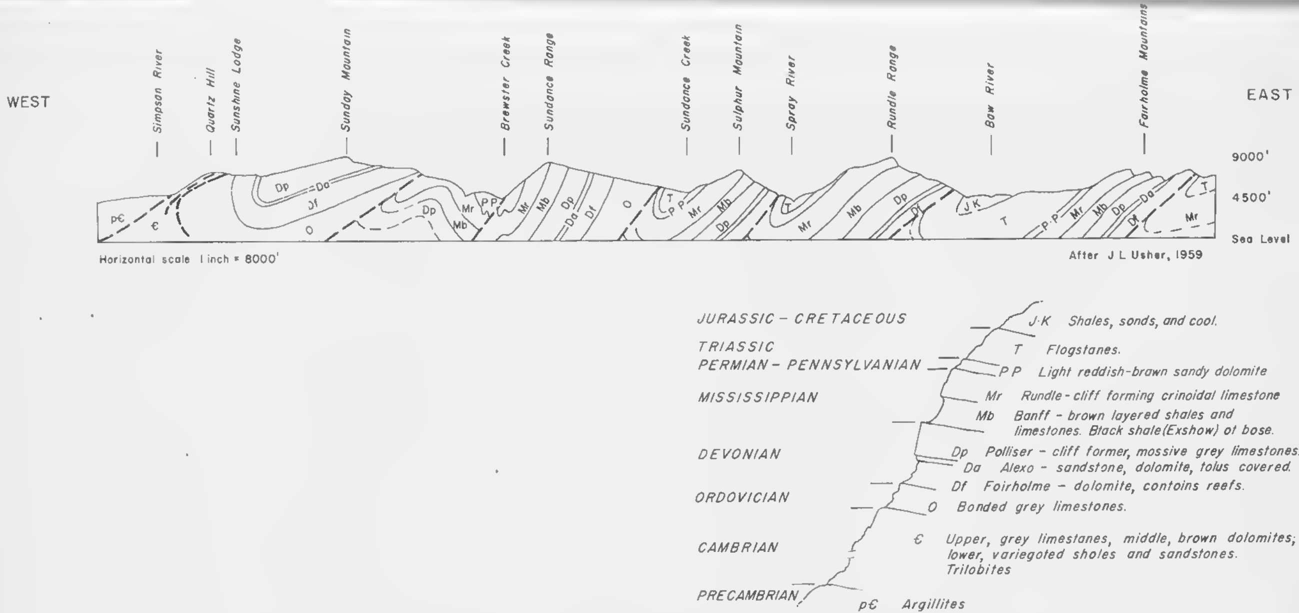

Figure 27. Diagrammatic section across the mountains from the Continental Divide at the headwaters of west flowing Simpson River and the east entrance to Banff National Park. Mount Rundle, as seen from the Hoodoos Viewpoint illustrates the alternating limestone cliffs and layered shale sequence typical of the Front Ranges of the Rocky Mountains east of Mount Eisenhower.

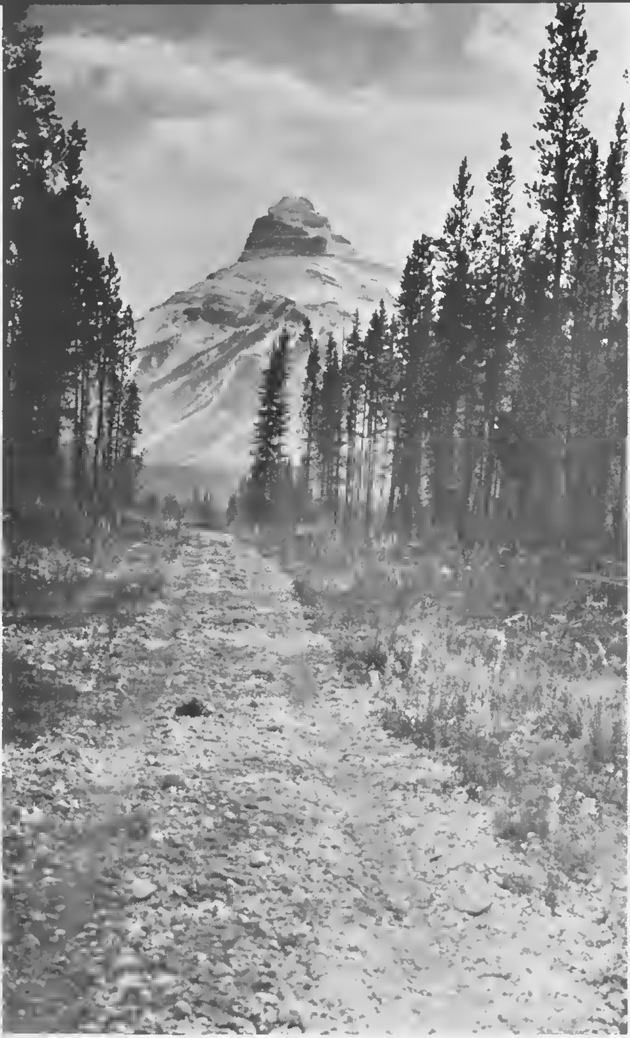

Figure 28. Pilot Mountain may be seen far a long distance up Baw River valley. It is capped by cliffs af the Mississippian Rundle formation that rest on layered Banff shales.

Figure 29. The Waputik Range and mountains in the Lake Louise areo. The rugged cliffs are mostly Cambrian limestones (C) and the lawer slopes Precambrian (PC) shales.

Figure 30. Moraine Lake in the Valley of the Ten Peaks near Lake Lauise. The Peaks ore cut in layered Lower Cambrian shales and quartzites. In the right background are recent glacial moraines left by glaciers that have retreated to the high peaks. Talus slapes fan outward and baulders af the rock slide dam the lake in the foreground.

Figure 31. Bow Lake, with Bow Glacier in the distance, near the headwaters of Bow River. The mountains are made up of Lower Cambrian quartzites and shales overlain by Middle Cambrian limestones. Bow Glacier is a tongue of the Wapta ice-field, barely visible at the top of the glacier. A delta (right centre) is being built into Bow Lake by the stream of meltwater from the glacier as it carries glacial debris downwards.

Figure 32. Hector Lake, west of the Banff-Jasper highway, is fed by glaciers along the Continental Divide. The cliffs are Middle Cambrian limestones dipping west away from the centre of Bow anticline.

Figure 33. Crowfoot Glacier. This glacier with its three claws grasping limestone rocks of Middle Cambrian age is a tongue of the Wapta ice-field. Moraines with sharp ridges are visible in the valley below the glacier.

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Alberta Government

Figures 8, 13, 33.

Royal Canadian Air Force

Figure 20.

Drawings by R. M. Proctor, Geological Survey of Canada.

Cover design, J.N. McCracken, Geological Survey of Canada.